



South Africa's Technical Readiness to Support the Shale Gas Industry

October 2016



science
& technology

Department:
Science and Technology
REPUBLIC OF SOUTH AFRICA



Academy of Science of South Africa
October 2016

ISBN 978-0-9946852-7-8

DOI: <http://dx.doi.org/10.17159/assaf.2016/0003>

Please use the DOI in citation.

Published by:

Academy of Science of South Africa (ASSAf)

PO Box 72135, Lynnwood Ridge, Pretoria, South Africa, 0040

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E-mail: admin@assaf.org.za

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The Academy of Science of South Africa (ASSAf) was inaugurated in May 1996. It was formed in response to the need for an Academy of Science consonant with the dawn of democracy in South Africa: activist in its mission of using science and scholarship for the benefit of society, with a mandate encompassing all scholarly disciplines that use an open-minded and evidence-based approach to build knowledge. ASSAf thus adopted in its name the term 'science' in the singular as reflecting a common way of enquiring rather than an aggregation of different disciplines. Its Members are elected on the basis of a combination of two principal criteria, academic excellence and significant contributions to society.

The Parliament of South Africa passed the Academy of Science of South Africa Act (Act 67 of 2001), which came into force on 15 May 2002. This made ASSAf the only academy of science in South Africa officially recognised by government and representing the country in the international community of science academies and elsewhere.



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TABLE OF CONTENTS

List of Figures	vi
List of Tables	vi
List of Acronyms	vii
Prefixes, Units and Gases	ix
Foreword	x
Acknowledgements	xi

EXECUTIVE SUMMARY 1

1 INTRODUCTION 17

1.1	Background to the Study	17
1.2	Study Methodology	17
1.3	Scope and Objectives of the Study	18
1.4	Overview	19

2 THE SHALE GAS DEBATE IN THE KAROO 23

2.1	What is Shale Gas and Where Does it Occur?	23
2.2	How is Shale Gas Accessed?	25
2.3	Potential Benefits of Shale Gas	26
2.4	Shale Gas Licencing and the Expected Start of Exploration in South Africa	26
2.5	Review of the Legal, Regulatory and Governance Aspects	27
2.5.1	Technical Regulations	27
2.5.2	Co-operative Governance (Chapter 3 of the Constitution)	28
2.5.3	Mineral and Petroleum Resources Development Act	29
2.5.4	Administration of Mining and Petroleum Laws	31
2.5.5	The National Environmental Management Act and Other Environmental Legislation	33
2.5.6	Astronomy Geographic Advantage Act	35
2.5.7	National Water Act	36
2.5.8	National Heritage Resources Act	37
2.5.9	Institutions	37

2.5.10	Human Resources for Implementation under the Minerals (MPRDA), Environmental (NEMA) and Water (NWA) Legislation	38
2.5.11	Summary	38

3 INTERNATIONAL PERSPECTIVES ON SHALE GAS 41

3.1	Introduction	41
3.1.1	Preamble	41
3.1.2	Challenges Facing Sustainable Energy Supply and Demand	41
3.1.3	In a Nutshell – What is Shale Gas?	43
3.1.4	What are the Benefits, and What are the Risks?	43
3.1.5	Retaining a Balanced Perspective	45
3.2	Overview of Shale Gas Development by Country	47
3.2.1	United States of America	47
3.2.2	European Union	47
3.2.3	United Kingdom	48
3.2.4	Poland	48
3.2.5	Germany	49
3.2.6	France	50
3.2.7	Canada	50
3.2.8	Australia	51
3.2.9	China	51
3.3	Key Lessons for South Africa	52

4 EVALUATION OF SOUTH AFRICA'S TECHNICAL READINESS TO SUPPORT A SHALE GAS INDUSTRY – FACTORS TO BE CONSIDERED IN THE PRE-PRODUCTION PHASE 55

4.1	Exploration to Evaluate the Shale Gas Potential of the Karoo	55
4.1.1	Shale Gases and Gas-Shales	55
4.1.2	Towards a Rigorous Scientific Exploration Programme for Gas-Shales in the Karoo	59
4.1.3	Summary	71
4.2	Issues of Water, Sand, Air and GHG Emissions	73
4.2.1	Introduction	73
4.2.2	Water and Chemical Requirements for Hydraulic Fracturing	75
4.2.3	Water Availability	80
4.2.4	Hydrogeology	81

4.2.5	Water Use Licence	83
4.2.6	Hydraulic Fracturing	84
4.2.7	Summary	85
4.3	Potential Impact on Astronomy	87
4.3.1	Preamble	87
4.3.2	Introduction	87
4.3.3	Review of Risks	88
4.3.4	Updated Assessment	91
4.3.5	Summary	91
4.4	Potential Socio-Economic Impacts	92
4.4.1	Introduction	92
4.4.2	Socio-Economic Profile and Challenges in the Central and Southern Karoo	93
4.4.3	Socio-Economic and Community Impacts Associated with Shale Gas Development	96
5	RATIONALE AND METHODOLOGIES FOR SHALE GAS BASELINE STUDIES	105
5.1	Introduction	105
5.1.1	Background	107
5.1.2	What in the Karoo is Foremost that must be Protected?	108
5.1.3	International Perspectives	109
5.2	Time Frames	110
5.2.1	Immediate Baseline Needs	111
5.2.2	Baseline Details for Long-Term Needs	113
5.3	Focus on Dynamic Water Baseline Studies	116
5.3.1	Reasoning and Implications	116
5.3.2	Problem Identification	117
5.3.3	Methodology	118
5.3.4	Details of Analyses and Interpretation	119

6 EVALUATION OF SOUTH AFRICA'S TECHNICAL READINESS TO SUPPORT A SHALE GAS INDUSTRY – FACTORS TO BE CONSIDERED IN THE PRODUCTION PHASE 123

6.1	Well Construction and Closure	123
6.1.1	Introduction	123
6.1.2	Amount and Quality of Water Required for Drilling a Well	125
6.1.3	Specification for Casing and Inspection Criteria	128
6.1.4	Reliability of Hangers in Casings	128
6.1.5	The Possibility of Using Production Casings to the Surface	129
6.1.6	Quality of Cement and Integrity	129
6.1.7	Cement Casings	131
6.1.8	Pressure Testing of the Well	134
6.1.9	Well Closure	134
6.1.10	Availability of Drilling Rigs in South Africa	135
6.1.11	Availability of Cement in South Africa	136
6.1.12	Availability of Casing in South Africa	137
6.1.13	Summary	137
6.2	Distribution and Exploitation of Shale Gas	139
6.2.1	Introduction	139
6.2.2	Gas-to-Electricity	143
6.2.3	Gas for Industry	144
6.2.4	Gas as Chemical Feedstock	145
6.2.5	Gas for Transport Fuels	146
6.2.6	Gas for Domestic Applications	148
6.2.7	Local Economic Development	149
6.2.8	Enabling Infrastructure	149
6.2.9	Summary	150
6.3	Capacity and Skills Development	150
6.3.1	Introduction	150
6.3.2	Skills Required for Developing the Shale Gas Industry in South Africa	151
6.3.3	Quantification	153
6.3.4	The <i>Status Quo</i> for Scarce Skills in South Africa	154
6.3.5	Matters of Concern Relating to Skills Development in the Short/Medium and Long Term	156

7 CONCLUSIONS AND RECOMMENDATIONS 161

7.1	Key Findings	161
7.1.1	International Perspectives	161
7.1.2	Exploration to Evaluate the Shale Gas Potential of the Karoo	161
7.1.3	Legal, Regulatory and Governance Aspects	162
7.1.4	Issues of Water, Sand, Air and GHG Emissions	163
7.1.5	Potential Impacts on Astronomy Activities	164
7.1.6	Socio-Economic Impacts of a Shale Gas Industry	165
7.1.7	Rationale and Methodologies for Baseline Studies in the Karoo	166
7.1.8	Well Construction and Closure	167
7.1.9	Distribution and Exploitation of Shale Gas	168
7.1.10	Capacity and Skills Development	169
7.2	Recommendations	169
	Glossary	177
	Bibliography	183
	References	187
	Appendices	209
	Appendix 1: Biographies of Panel Members	209
	Appendix 2: Biographies of Reviewers	211
	Appendix 3: Proposed Core Research Projects	212

LIST OF FIGURES

Figure 3-1: Sustainable primary energy exploitation has four elements, each of which is of crucial importance	42
Figure 3-2: Technically recoverable resource (TRR) potential of shales in the countries under study in this report (US EIA, 2013a)	43
Figure 3-3: The Argument Map lays out the pros and cons of shale gas exploitation in a logical manner (www.shale-gas-information-platform.org/)	46
Figure 4-1: Simplified geology and shale gas parameters of the Karoo, highlighting the areal extent most favourable to explore for shale gas (brown area; approximately 79 - 92 000 km ²)	57
Figure 4-2: Summary map of potential shale gas locations in the southern Karoo, relative to important potential constraints limiting its exploration/exploitation (AEON Map using Google and digital geologic and ecological information)	72
Figure 4-3: Map indicating the SKA Phase 1 and Phase 2 configuration, superimposed over the identified shale gas exploration areas in the Karoo region	89
Figure 4-4: Location of the Karoo Basin and the exploration areas in relation to national provinces, as well the locations of the SALT and SKA activities (www.karoospace.co.za)	93
Figure 5-1: Interrelated issues and impacts associated with shale gas development (Modified for the Karoo from Zoback and Arent, 2014; Morkel and De Wit, 2016)	106
Figure 5-2: Relationship between determinants from different groundwater sources (Modified from O'Brien <i>et al.</i> , 2013)	120
Figure 6-1: Direct and indirect water use for a shale gas/oil well (Jiang <i>et al.</i> , 2013)	126
Figure 6-2: Scenario of unwanted fluid flow (www.shale-gas-information-platform.org)	131

LIST OF TABLES

Table 1-1: Composition of the study panel	17
Table 4-1: Typical hydraulic fracturing fluid additives (ACOLA, 2013)	68
Table 4-2: Estimates of water use for hydraulic fracturing	79
Table 4-3: Sources of water supply for some Karoo towns (DWA, 2011a and b).	81
Table 6-1: Future cement demand	136
Table 6-2: Onshore skills overview of manpower demand	153

LIST OF ACRONYMS

AAA	Astronomy Advantage Area
ACOLA	Australian Council of Learned Academies
AEON	African Earth Observation Network
AGA	Astronomy Geographic Advantage
API	American Petroleum Institute
ASME	American Society of Mechanical Engineers
ASSAf	Academy of Science of South Africa
BCF	Billion cubic feet
BGR	<i>Bundesanstalt für Geowissenschaften und Rohstoffe</i>
BGS	British Geological Survey
BOP	Blow out preventer
BP	British Petroleum
CBL	Cement bond log
CEF	Central Energy Fund
CEO	Chief Executive Officer
CNG	Compressed natural gas
CSIR	Council for Scientific and Industrial Research
CTL	Coal-to-liquid
DEA	Department of Environmental Affairs
DECC	Department of Energy and Climate Change
DHA	Department of Home Affairs
DHET	Department of Higher Education and Training
DMR	Department of Mineral Resources
DoE	Department of Energy
DST	Department of Science and Technology
dti	Department of Trade and Industry
DWS	Department of Water and Sanitation
EA	Environmental assessment
EIA	Environmental impact assessment
EMI	Electromagnetic interference
EMP	Environmental management plan
EMRI	Environmental Management Resource Inspector
EN	Euro specification
E&P	Exploration and Production
EU	European Union
GDP	Gross domestic product
GHG	Greenhouse gas
GJ	GigaJoules
GTL	Gas-to-liquids
GUMP	Gas Utilisation Master Plan
HFMC	Hydraulic Fracturing Monitoring Committee
HFO	Heavy fuel oil
IDP	Integrated development planning
IEA	International Energy Agency

IEP	Integrated Energy Plan
IRP	Integrated Resource Plan
ISO	International Organisation for Standardisation
IWULA	Integrated Water Use License Application
LNG	Liquefied natural gas
LPG	Liquefied petroleum gas
LUPO	Land Use Planning Ordinance
MEC	Member of the Executive Council
MPRDA	Mineral and Petroleum Resources Development Act
MT	Magnetotelluric
NDP	National Development Plan
NEMA	National Environmental Management Act
NERSA	National Energy Regulator of South Africa
NGO	Non-Governmental Organisation
NMMU	Nelson Mandela Metropolitan University
NORMs	Natural occurring radioactive materials
OBM	Oil-based muds
OCGT	Open cycle gas turbine
OFO	Organising Framework for Occupations
OPPPW	Polish Exploration and Production Industry Organisation
PASA	Petroleum Agency of South Africa
PetroSA	Petroleum Oil and Gas Corporation of South Africa
RFI	Radio frequency interference
ROMPCO	Republic of Mozambique Pipeline Investment Company
SAAE	South African Academy of Engineering
SAAO	South Africa Astronomical Observatory
SADC	Southern African Development Community
SALT	Southern African Large Telescope
SAEON	South African Environmental Observation Network
SAOGA	South African Oil and Gas Alliance
SBM	Synthetic-based muds
SCA	Supreme Court of Appeal
SEA	Strategic environmental assessment
SETA	Sector Education Training Authority
SGD	<i>Staatlichen Geologischen Dienste der Deutschen Bundesländer</i>
SIP	Strategic infrastructure project
SKA	Square Kilometre Array
SKUHS	Succulent Karoo UNESCO World Heritage
SOE	State-owned enterprise
SOEKOR	Southern Oil Exploration Corporation
SPLUMA	Spatial Planning and Land Use Management Act
SRV	Stimulated reservoir volume
tcf	Trillion cubic feet
TDS	Total dissolved solids
TKAG	Treasure Karoo Action Group
TOC	Total organic content
TRR	Technically recoverable resource

UK	United Kingdom
US EIA	Energy Information Agency (USA)
USA	United States of America
UTT	Upstream Training Trust
VOC	Volatile organic carbon
WBM	Water-based muds
WRC	Water Research Commission

PREFIXES, UNITS AND GASES

Gases (units of measurement)		
Prefix	Symbol	Power
Kilo	K	10 ³
Mega	M	10 ⁶
Giga	G	10 ⁹
Tera	T	10 ¹²

Units of measurements			
Unit	Definition	Unit	Definition
a	Annum	bbbl	Barrel
btu	British thermal units	h	Hour
J	Joule	mD	Millidarcies
mtoe	Million tonnes of oil equivalent	tcf	Trillion cubic feet
W	Watt	We	Watt electricity

Gases			
Unit		Unit	
CH ₄	Methane	NO _x	Nitrogen oxides
CO ₂	Carbon dioxide	SO _x	Sulphur oxides

Currency		
R - Rand	\$ - United States Dollar	€ - Euro

FOREWORD

The Academy of Science of South Africa (ASSAf) is mandated to provide evidence-based science advice to government on matters of critical national importance. The South African National Development Plan (NDP) has identified the need for sustainable economic growth in tandem with skills development and job creation. These objectives cannot be met without sustainable energy generation.

The strategic issues of sustainable energy, skills development and job creation are all addressed in this report on the technical readiness of South Africa to support the shale gas industry. The study has followed the traditional Academy consensus study methodology and was carried out by a panel of experts, guided by a panel chair. All served in a voluntary capacity. The advantage of this multi-perspective, evidence-based approach is that it is free of partisan interest. As a result, the findings and recommendations are the best considered outcomes in the circumstances.

This report assesses the *status quo* with regard to available information and technologies in South Africa, and links the findings with the needs of the shale gas activities if such an industry were to develop. The report makes several recommendations for future data collection and research to prepare South Africa for a shale gas industry, and suggests important interventions that would need to be considered to enable the development of the industry.

The study has benefited from comprehensive reports undertaken by academies of science in Australia and Canada. Both local and international panel members have interpreted these findings within a South African context and have produced a uniquely South African report. South Africa has much to learn from the international experience as it carves its way forward in this field.

I acknowledge with thanks the valuable work carried out with care and attention by the members of the study panel, the authors of the report, as well as those Academy staff members who have been involved in this study.

Professor Daya Reddy
President: Academy of Science of South Africa

ACKNOWLEDGEMENTS

This study was a collaborative effort involving many dedicated people. I wish to thank the following people and organisations for ensuring the success of the study:

- The Academy of Science of South Africa, the President of ASSAf, Prof Daya Reddy, and the Council for their ongoing support throughout the project.
- The Department of Science and Technology (DST) for commissioning and funding the project, and in particular Mr Somila Xosa, the Director of Transport Fuels, DST, for his guidance and support.
- The members of the consensus study panel for their commitment, time, effort and valuable contributions to the report.
- Dr Johann Pauw of the South African Earth Observation Network (SAEON) and Dr Peter Martinez of the South African Astronomical Observatory (SAAO) for their presentations to the panel.
- The authors, other than the panel members, who assisted by writing sections of the report. They include:
 - Prof Brian Horsfield of Helmholtz-Centre Potsdam – German Research Centre for Geosciences (GFZ);
 - Prof Jan Glazewski of the Institute of Marine and Environmental Law, University of Cape Town;
 - Dr Adrian Tiplady of the Square Kilometre Array (SKA);
 - Mr Barry Morkel of the Africa Earth Observatory Network (AEON) – Earth Stewardship Science Research Institute, Nelson Mandela Metropolitan University;
 - Prof Gerhard Thonhauser, with the assistance of Mr Mathias Mitschanek, of the Department of Mineral Resources (DMR) and Petroleum Engineering, University of Leoben in Austria;
 - Prof Jim Petrie of the Department of Economic Development and Tourism, Western Cape Government;
 - Mr Dave Wright of Dave Wright Consulting.
- The peer reviewers who gave valuable input that allowed improvement of the report.
- The copy editor, Ms Patricia Scholtz and Fishwicks for attention to detail and the production of the report.
- The staff of the Academy, in particular, Prof Roseanne Diab, Ms Nadia Weitz and Mr Ian Shendelana, for their contribution and support throughout the project.

Prof Cyril O'Connor
Chair of the Panel



EXECUTIVE SUMMARY



South Africa's National Development Plan (NDP) has prioritised the need for economic growth to be closely linked to sustainable energy production, skills development and job creation. The South African national government is looking to shale gas development in the Karoo to contribute to these objectives.

In recent years the discovery of very large shale gas resources and the exploitation of shale gas (and shale oil) reserves in countries such as in North America, has transformed the energy market. South Africa is considered to possess potentially large resources of shale gas and if South Africa decides to exploit these resources it is possible that this may be a 'game changer' with respect to our energy balance. However, it is well known that the exploitation of these key energy resources and reserves may present some significant environmental, technical, social and economic challenges. Hence it is of critical importance that all these matters be carefully analysed.

The Academy of Science of South Africa (ASSAf) was requested by the Department of Science and Technology (DST) to conduct an assessment of the technical readiness of South Africa to support the shale gas industry. ASSAf partnered with the South African Academy of Engineering (SAAE) in this study. The study adopted an approach of a consensus study in which a panel of experts appointed by the ASSAf Council committed, voluntarily, to undertake the necessary tasks to provide an assessment. The panel relied on a number of sources for information and evidence, in addition to requesting investigations to be undertaken by specialists into specific topics to provide the panel with the necessary information.

The main focus areas of the study are: international perspectives and experiences related to shale gas; technologies and capabilities related to exploration for shale gas, drilling and extracting shale gas, as well as distribution and exploitation of shale gas; legal, regulatory and governance aspects related to shale gas activities and developments; the potential impacts on water availability, water quality, and sand, air and greenhouse gas emissions; potential impacts on activities of astronomy research and on the local and regional socio-economic activities; the national availability of the necessary skills and human capacity; and, finally, the availability of baseline information on the local environment prior to the commencement of any exploitation of shale gas.

In order to introduce the study, **Chapter 2** provides a brief overview on the history of shale gas developments and activities in South Africa, including a geological review on the formation of shale gas in the Karoo. This chapter concludes with a narrative on the recent events of licencing and permitting in South Africa.

Chapter 3 provides a global view of the shale gas industry and offers an opinion on sustainable energy exploitation, with a description on risks and benefits of embarking on a shale gas industry using hydraulic fracturing. The remainder of the chapter presents assessments of the current situation and the future of shale gas in the United States, Europe (United Kingdom (UK), Poland, Germany and France), Canada, Australia and China.

The factors to be considered in terms of technical readiness with respect to pre-production of shale gas are discussed in **Chapter 4**. The chapter opens with a detailed description of the formation of shale and shale gas reservoirs in South Africa in introducing the technical readiness in terms of exploration. A two-step process of exploration is proposed, beginning with sub-surface geological investigations to determine the depth, thickness and physico-chemistry of the shale gas sequence, and culminating in an experimental hydraulic fracturing 'laboratory' to assess whether shale gas can indeed be efficiently extracted. Further to this, the actual process of hydraulic fracturing – in geological terms – as well as the techniques and requirements of hydraulic fracturing is described.

Following the section on exploration, an analysis of the regulatory environment is provided. A synopsis is provided on the sequence of events that led to the ultimate lifting of the moratorium in November 2013, and the publication of the Proposed Technical Regulations for the Exploration and Exploitation of Petroleum Resources. These regulations, together with the relevant rights (the Environmental Right, the Right to Just Administrative Action, the Right of Access to Information and the Right to Sufficient Water) and acts (the Minerals and Petroleum Resources Act, the National Environmental Management Act, the Astronomy Geographic Advantage Act and finally, the National Water Act) are also discussed. Co-operative governance issues are also highlighted in terms of administration between the various government departments and various levels of governance (national, provincial and municipal).

Also within the chapter on technical readiness related to the pre-production phase are sections on the potential impact on water availability, water quality, sand and air, the potential impacts on astronomy research activities and on the socio-economic setting of the Karoo. In terms of water availability and water quality, the potential impacts are particularly contentious issues. The volumes of water required for the hydraulic fracturing process, as well as the possible impacts on water quality, necessitate that a holistic approach be followed in addressing these concerns, as both surface water and groundwater could be impacted upon. Within this section, the requirements for water and chemicals are described; details on the current status of water availability and water supplies in the Karoo are provided; the geology and hydrogeology are discussed; and all is then contextualised in terms of the requirements for hydraulic fracturing.

In terms of the potential impact on astronomy research activities, the study submitted to the Department of Mineral Resources in 2013 was revisited by the original author. No further evidence could be sourced, but the risks were reviewed and the regulations reiterated.

Importantly, the existing situation in terms of the socio-economic environment of the Karoo is presented as the last section of Chapter 4. The history of industrial development in the area provides context for the potential impacts due to shale gas development. The risk factors that should be considered as part of the ongoing discourse on shale gas development in South Africa are described. Although the section touches on international experiences with socio-economic impacts, it does not prescribe that the same holds true for South Africa. Thereafter, the likely impacts in terms of human health and safety, social and political risks, socio-economic and finally, governance and institutional aspects, are addressed.

Chapter 5 presents the argument for baseline studies that should take place prior to any developments related to shale gas exploitation and outlines in detail the nature of such proposed baseline studies. A series of baseline studies would enable the establishment of knowledge and relevant information on key attributes or characteristics of the situation prior to the commencement of prospective exploration/exploitation for shale gas in the Karoo. Without such baseline information, prosecution or potential litigation against non-compliant practitioners may prove almost impossible. Such studies will also contribute significantly to a more in-depth understanding of the best practices that should be adopted once exploitation commences.

The next chapter, **Chapter 6**, on South Africa's technical readiness to support the shale gas industry investigates technical issues related to production and post-exploration issues. The chapter starts with a comprehensive description of the life cycle of a well, including drilling and well closure and abandonment. All aspects of drilling requirements, techniques, materials and equipment are discussed, followed by an investigation into the availability of the necessities in South Africa. In addition to the innate requirements of well creation, closure and abandonment, the human capacity required during the life cycle of the well is outlined.

Following the discussion on drilling and gas extraction, is an investigation into the exploitation of shale gas, including the potential for a gas-based economy in South Africa. The various options available for gas usage are described, and the likelihood of a gas market in South Africa is assessed.

The last section is related to technical readiness with respect to human capacity and skills availability. This section first assesses the skills required to support the shale gas industry, including a more defined estimate as to the quantum of human capacity required and current availability.

The conclusions and subsequent recommendations are presented in **Chapter 7**. With regard to *international perspectives and lessons*, South Africa urgently needs to assess its technically recoverable resources because the security of domestic energy supply is of fundamental importance. The country must commit to a balanced long-term shale gas exploitation strategy based upon the four elements of sustainability, viz. security of supply, efficiency of extraction, environmental protection and societal communication. It is important that South Africa builds upon the experience gained through shale gas and shale oil developments that

continue to take place in the USA, Europe, Asia and Australia, fully utilising the wealth of published facts made available by reputable scientific bodies.

Following the examples of countries such as the UK, Germany, Poland, Canada and Australia, South Africa must conduct its own baseline studies in order to determine unambiguously the potential environmental impingement which may occur during shale gas exploration and exploitation by industry. The country must also expand its interaction and collaboration with the world's leading professional and academic institutions to facilitate knowledge transfer, establish state-of-the-art working protocols and conduct regional as well as site-specific environmental monitoring. Balancing the economic and environmental attributes of sustainability is of fundamental importance. In this regard, space must be opened for greater civil society participation within ongoing processes.

In terms of ***exploring to evaluate the shale gas potential in the Karoo***, presently the Karoo shale gas is a potential reserve with at least 19 and 23 trillion cubic feet (tcf) of available free gas across an area of approximately 60 000 - 100 000 km². However, the three-dimensional (3-D) geology of the Karoo is poorly known, and remote geophysical sensing and deep-cored drill-holes will need to be implemented during a first exploration phase to determine subsurface distribution of gas-shales and the location of 'sweet spots' so as to establish with greater accuracy the total potential recoverable amount of shale gas in place. Limited multi-directional hydraulic fracturing at three to five pads will be needed during a second exploration phase to evaluate the retrieval success of the shale gas and how efficiently the gas can be harvested to determine its economic return and its status as gas reserve. During both phases of shale gas exploration, quantitative knowledge of groundwater resources of the Karoo will vastly improve. For both these stages of shale gas exploration, it must be appreciated that there are local skills shortages and lack of the equipment and basic infrastructures required for such studies.

South Africa has a history of inadequate controls when it comes to externality costs related to mining and abandoned mines. This must be avoided at all costs in the case of shale gas exploitation in the Karoo, starting from the first exploration phase. A major recommendation to address all of the above-mentioned needs, is for South Africa to design and build an experimental drilling and hydraulic fracturing research laboratory. It should be linked to a technical shale gas training college possibly located in the Eastern Cape, where drilling experiments and hydraulic fracturing tests can be carried out under controlled conditions and with a mandate to drive new science, engineering and technology skills. It must aim to attract competent researchers and mentors to help develop local persons with the requisite monitoring skills, as well as develop the appropriate regulatory requirements required to ensure a competent, compliant and transparent shale gas industry.

Within the realm of ***regulations and policy***, the environmental impact assessment (EIA) procedure together with the environmental management plan (EMP) process, driven by the Department of Environmental Affairs (DEA) and the Department of Mineral Resources (DMR) under the National Environmental Management Act and

the Minerals and Petroleum Resources Act respectively, are central in ensuring the success of the upstream to downstream shale gas enterprise. The recent establishment of a task team to undertake a strategic environmental assessment (SEA) is welcomed. It should contribute significantly to determining the most economically, socially and environmentally optimal gas source to be exploited for the country. Such a study would identify alternative sources of both conventional and unconventional sources and weigh up the costs and benefits to South Africa of each.

Upstream to downstream shale gas activities require intergovernmental collaboration and the cooperation of a wide range of national government departments, as well as potentially affected provinces and municipalities. Hence it will be necessary to establish both an 'inter-agency' statutory body whose overall function will be to promote and facilitate the development of the onshore and offshore oil and gas industry in South Africa, and, at the same time, to establish an independent monitoring committee which includes both government and non-government participants in order to ensure the effective and transparent implementation, monitoring and compliance of all shale gas-related activities with existing laws and regulations applicable to shale gas extraction.

It is estimated that an initial exploration programme (including evaluating seismic activities and gas harvesting potential) will last at least five years. This period provides opportunities to carry out and conduct vital baseline studies, as well as to assess the technical and human capacity needs. It will be necessary to ensure that the granting of exploration licences is conditional on the licensee carrying out further independent feasibility, social and environmental studies prior to the issuance of a production licence.

Water requirements for hydraulic fracturing and the likely flowback of returned "frack-fluid" and production water, which should preferably be recycled, are unlikely to be determinable until after trial hydraulic fracturing is undertaken during initial exploration tests. Whatever the volume required, the preferred sources of water supply would be deep saline aquifers, although the importation of water by pipeline or truck is another, but less attractive, possible option. Similarly, the disposal of excess flowback should also be carefully managed. Licences for water use and the disposal of flowback fluids would be required and would need to be determined in accordance with the National Water Act that is administered by the Department of Water and Sanitation (DWS).

Robust strategies must be implemented to determine source apportionment of methane (CH₄) emissions and the quantification of local atmospheric CH₄ concentrations before and after the start of exploration. This will require continuous ground and airborne monitoring of CH₄ leakage to determine greenhouse gas footprints of all sources across the Karoo.

Proppants used for hydraulic fracturing are likely to be sourced from local suitable dune-sand deposits which exist in South Africa and along its coastal margins, but these are mostly environmentally sensitive and often in protected

areas. Environmental (land use, water needs) and health issues (silicosis, industrial accidents) associated with sand mining, processing, and transportation are well understood and for shale gas exploitation this must be continuously monitored when such material is transported across the Karoo.

In terms of potential impacts on astronomy research activities, it was noted that shale gas-related operations present a significant risk to the scientific performance of the Square Kilometre Array. Part of this risk is as a result of the uncertainty that arises from a lack of information on specific shale gas industry activities, such as deployment strategies, site specific analyses, equipment usage (characterised in terms of electromagnetic interference), and supporting activities. All shale gas operations will need to be fully compliant with all the provisions of the Astronomy Geographic Advantage Act.

Related to the **socio-economic impacts**, there is a need for assessing risks, and for studies to assess, quantify and ultimately manage both the concomitant externality and opportunity costs of pursuing a shale gas industry. In addition, there is a need for an appropriately wide-reaching public consultation and awareness programme in the Karoo.

There is perhaps a five-year window of opportunity to gain a clear understanding of the present state of the Karoo and its underground water systems and surface environments, and to use this to establish a forensic **baseline across the Karoo**. Without such a baseline investigation, underpinned by a good understanding of the hydrogeology/geophysics, any possible contamination of groundwater or destruction of ecosystems related to hydraulic fracturing and harvesting of gas cannot be determined with sufficient accuracy or proven beyond reasonable doubt thus rendering litigation related to any damage arising from shale gas exploitation and externality costs of exploitation of the gas almost impossible.

It is therefore critical to clearly establish baseline conditions before the commencement of shale gas exploitation and to use multiple lines of evidence to better understand issues such as gas migration and possible chemical pollution. Such a set of studies is a critical precursor to the commencement of the industry and, in this regard, South Africa has a unique opportunity to be a global exemplar, given that to date such studies have not been done in countries in which hydraulic fracturing is practised.

The know-how, technology, and most equipment required for virtually all needed scientific baseline studies, and continuous monitoring thereafter, are generally not presently available at South African academic research institutions or at its science/research councils. To address these shortcomings, it is therefore recommended that South Africa takes the necessary steps to invest in academic institutions or science councils. Such an intervention could be enhanced through the establishment of an experimental 'Karoo Shale Gas Laboratory' associated with a 'Training College', where the relevant skills required by the industry can be developed.

It is important to appreciate that shale gas development is a manufacturing process unlike conventional oil and gas developments on and offshore. Consequently, it is necessary, for example, to build and develop on an ongoing basis a robust field development model to understand and plan all relevant technical aspects associated with shale gas development. This will require undertaking pilot field development studies as part of the exploration phase. The local technical baseline information thus obtained will be used as input to the model (water usage, resource requirements, and emissions). Such information should be obtained within six to 12 months of the exploration licence being awarded. Without this information, strategic decisions relating to production licensing agreements with potential operators will be inadequate. Special challenges related to **shale gas drilling in South Africa** include issues relating to the provision of an adequate number of rigs, availability of casings and cementation procedures which are compliant with best practice.

In terms of **gas exploitation**, the South African gas market is potentially large. Whilst the future of the shale gas opportunity is being assessed (five to ten years), there is an opportunity to develop anchor markets based on compressed natural gas and liquefied natural gas imports. Gas-to-power projects are essential for this development and although there is a strong commercial appetite for investing in the requisite infrastructure, the limiting constraint presently is national energy policy and regulation. A revised Integrated Resource Plan for electricity (IRP 2010 update) is needed to address this matter and the role of natural gas re-emphasised in the light of changed conditions since the original modelling was undertaken. At the same time, a 'whole of government' approach should be implemented as soon as possible to ensure the effective use of natural gas within South Africa's energy economy.

In terms of **human capacity and skills availability**, the number of jobs that shale gas development will create is still difficult to quantify given the lack of clarity around the size of the resource and how it can be exploited. It is however clear from the little data available that most of the new jobs will be in the upstream activities and the skills in this area are in extremely short supply, or are arguably non-existent, in South Africa. Consequently the need to access these skills will present a serious challenge in developing any unconventional gas resource in the country. Hence, initially all skills required for the upstream shale gas sector will need to be imported and this will require a mixed approach, divergent from 'business as usual', if risks are to be mitigated and benefits accrued through the sector. It will require a scaled approach with clearly defined long, medium, and short-term strategies for developing the necessary local skills across the value chain. Emphasis will need to be placed on both government and industry requirements, with a special emphasis on developing compliance monitoring and environmental management capacities. In the short term, the development of local skills will require operators to provide on the job training and development for people from the secondary and tertiary education systems. This will require that companies licensed to carry out shale gas development in South Africa should be obliged to contribute to the up-skilling of these entry-level people.

The final chapter concludes with recommendations aimed at ensuring the technical readiness of South Africa to support a shale gas industry. Not all of these recommendations for action lie directly within the area of responsibility of the DST and a number are clearly for the attention of other government departments. All of the recommendations, however, are considered to be directly relevant to the mandate given for this study.

The recommendations emanating from this study have been clustered into two groupings, viz. those which are directly for the attention of the DST and those for which the responsibility is located in other departments. This latter group is clustered for the purposes of this report as being for the attention of the Hydraulic Fracturing Monitoring Committee (HFMC).

RECOMMENDATIONS	SPECIFIC ACTION REQUIRED BY DST
<p>1 A pre-requisite for South Africa to consider itself technically ready to implement a shale gas industry is that the DST, in consultation with other relevant departments, should initiate a major project to undertake robust interdisciplinary, regional and local baseline studies to establish a body of knowledge on the <i>status quo</i> with regard to a range of issues at this critical juncture, prior to commencement of shale gas exploration/exploitation. The initiation of baseline monitoring should form the basis of an ongoing monitoring network. This must include acquisition of both surface and deep terrestrial data. While it is recognised that there are several organisations (e.g. SAEON) currently involved in baseline monitoring, and that recently an SEA task team has been established, it is necessary to coordinate these efforts and to extend the monitoring to below the surface. The DST should convene a public engagement event with active organisations to assess the status and level of ongoing activity in terms of studies contributing to baseline information.</p>	<p>Recommendations for effective baseline studies to improve current knowledge of the shale gas potential and its effects on the natural and social Karoo systems.</p> <p>Objective: Design and implement a multi-disciplinary research programme to determine the natural and social state of the Karoo prior to the commencement of exploration and exploitation of shale gas, through linking chemical, biological and medical forensics to core spatial surveys (mapping) based on state-of-the-art surface, air and remote sensing techniques using satellite and geophysics technologies and selected drilling. Such a study must include the following:</p> <ul style="list-style-type: none"> • Surface water, groundwater/ aquifer monitoring and analyses to determine the natural chemical variability of water across the Karoo, and to further determine the quality and quantity of underground water reservoirs and water flow.

RECOMMENDATIONS	SPECIFIC ACTION REQUIRED BY DST
<p>Given the multi-disciplinary nature of the data required and the provision of a database that will inform all related research activities, the DST is clearly the lead department to oversee this task. The data collected should be archived in an open database management system to facilitate transparency and to foster research. It is emphasised that it is important for such monitoring to commence as soon as possible and that the monitoring must be sustained for the long term.</p>	<ul style="list-style-type: none"> • Micro-earthquake detection and deep-subsurface imaging of the Karoo, to determine the natural seismic activity, ambient noise and stresses, and variations in levels of tectonic stability across the region; and to determine the structure of the subsurface and fluid (water, gas) pathways beneath the Karoo. • Image the 3-D geology of the Karoo, to determine possible variability of saline water resources and identify shale gas and radioactive hotspots, and deep fault systems. • Gas flow detection, to determine the location and flux of natural gas leakage (methane and carbon dioxide) across the Karoo region. • Variations of surface and critical zone (soils) ecosystems, to monitor their natural long and short-term variability and to model potential effects of disaggregation on the landscapes and other natural life-support systems. • Geology and geo-engineering analyses, to determine rock and soil properties and palaeostress systems and erosion rates. • Controlled drilling and geo-engineering experiments through a rural 'Karoo Shale Gas Experimental Laboratory' (cf. Recommendation 3 below) to scientifically test and model induced seismicity, fracturing, and flow of gas-water-chemicals using a controlled single well, multi-directional-hydraulic-fracturing site.

RECOMMENDATIONS	SPECIFIC ACTION REQUIRED BY DST
	<ul style="list-style-type: none"> • Socio-economic assessments to provide robust economic evaluations of the potential impact/risks of developing shale gas in terms of land value, agriculture, job creation, socio-economic development and downstream effects of gas as a manufacturing industry. • Monitoring the health and well-being of humans and livestock to determine potential effects of social disruptions and unexpected externalities. • Database management and numerical modelling abilities to enable growth and sharing of baseline knowledge through open-source database access, and to enable multi-variate testing of changes to the natural state of the Karoo Basin.
<p>2 A major priority for the technical readiness of South Africa to implement a shale gas industry is the need to establish processes to continuously and accurately monitor, from the outset, key factors which will impact on the long-term sustainability of the industry such as amounts of gas extracted, water usage, flowback water produced, gas utilisation, transportation requirements, other environmental impacts, etc.</p>	<p>Within 12 months of the award of the licence, operators must provide the relevant authorities with results from the following tests:</p> <ul style="list-style-type: none"> • 3-D analyses based on continuous down-the-hole data acquired during the drilling of vertical wells. • Limited multi-directional hydraulic fracturing at selected pads must be done to evaluate the retrieval success of the shale gas, water usage, flowback water produced, gas utilisation, transportation requirements, etc. <p>Following this exploration phase, any abandoned wells must be properly closed using best sealing practices.</p>

RECOMMENDATIONS	SPECIFIC ACTION REQUIRED BY DST
<p>In order to achieve this, recipients of exploration licences should be required to perform pilot field development studies and to provide the above-mentioned data for input into the field development model. The model will enable robust predictions to be made of the long-term impact of developing many such wells. Such an exercise will be ongoing throughout the life of the industry and will contribute to a continuous environmental impact assessment. No hydraulic fracturing should be permitted within 1 500 m of the surface.</p> <p>This exercise is not to be confused with the baseline studies recommended in 1 above which should take place before any commercial activity commences.</p>	
<p>3 A major priority for the technical readiness of South Africa to implement a shale gas industry is to ensure that the skills and infrastructure required to implement such an industry are available. The technological know-how and equipment required for virtually all scientific baseline studies, the continuous compliance monitoring thereafter by skilled regulators, well development, etc., is not generally available in South Africa (e.g. Sections 4.2, 6.1 and 6.3 of the report). There is moreover minimal expertise at our universities in unconventional gas exploration and its potential downstream development.</p>	<p>A comprehensive review of the state of shale gas research in South Africa should be undertaken to determine any gaps in the capacity of the higher education institutions (HEIs) to provide the skilled people required for the industry. This exercise to determine such needs should include an engagement with the industry.</p>

RECOMMENDATIONS	SPECIFIC ACTION REQUIRED BY DST
<p>It is critically important that operators will be required to be fully compliant with all the conditions associated with the award of a licence and this will require the availability of technically competent regulators.</p> <p>The industry will initially be dependent on importing high-level skilled people but in the long term the local educational institutions must provide the necessary skilled workforce for the industry.</p>	<p>Consequent on such an analysis, consideration should be given to interventions such as:</p> <ul style="list-style-type: none"> • Strengthening local research capacity through the establishment of appropriate research chairs and/or centres of research excellence and the provision of the necessary high-tech equipment for carrying out the functions referred to elsewhere in these recommendations. • Establishing a 'Research Laboratory and Training College' preferably in the Eastern Cape and associated with a local HEI to help develop a local skilled workforce and to provide in-service training opportunities for students from HEIs. <p>In the short term, it will be necessary to import people with the required upstream/technical and regulatory skills to assist in the initial phase of the development of the industry and to provide the appropriate training programmes.</p> <p>It is clear that implementing such a recommendation will require interactions with the Department of Higher Education and Training (DHET) and the Department of Home Affairs (DHA) as appropriate.</p>

RECOMMENDATIONS	SPECIFIC ACTION REQUIRED BY HYDRAULIC FRACTURING MONITORING COMMITTEE (HFMC) OR EQUIVALENT
<p>4 In order to ensure the technical readiness of South Africa to implement a shale gas industry and to achieve optimally many of the objectives set out in the DST-related recommendations it will be necessary that immediate steps should be taken to establish a new, or strengthen an existing, government agency whose overall function is, <i>inter alia</i>, to enable and facilitate the development of the shale gas industry in South Africa. This designated agency must coordinate licensing, monitoring and regulatory functions in consultation, as necessary, with all the relevant government departments.</p>	<p>The HFMC must ensure, if not already done so, the establishment of a single body:</p> <ul style="list-style-type: none"> • to act on their respective behalves as the interface between the various ministries involved in hydraulic fracturing and potential licence applicants/holders; • to coordinate the oversight, monitoring and regulatory functions needed to ensure full compliance of all operators with the terms and conditions of the licence agreements.
<p>5 An assessment of the economic implications of shale gas development for South Africa must be undertaken to critically assess the supply-demand situation. This should include an assessment of the potential of shale gas to significantly impact on the national energy requirements. It will be necessary to commit public sector funding to gas transmission and distribution infrastructure in order to develop gas markets which are currently based on imports.</p>	<ul style="list-style-type: none"> • Previous such assessments should be reviewed in the light of recent economic developments in the oil and gas industries • The Gas Utilisation Master Plan (GUMP) must be incorporated into the national plan for the implementation of a shale gas industry and such information must be incorporated into the field development model (cf. Recommendation 2 above).

RECOMMENDATIONS	SPECIFIC ACTION REQUIRED BY HYDRAULIC FRACTURING MONITORING COMMITTEE (HFMC) OR EQUIVALENT
<p>6 Although the challenges to ensure the country's technical readiness can be addressed successfully, it is nevertheless strongly recommended that the HFMC implement a comprehensive public consultation and engagement process with local communities in the Karoo that should:</p> <ul style="list-style-type: none"> • include the need for a fact-based information sharing programme, and which is independent of prospective operators and other sectional interested parties; • give due attention to the prevailing environmental and social concerns, expectations, and interests of all local communities; • include issues relating to the principle of local and regional beneficiation and participation in shale gas development in the Karoo Basin. 	<p>The public consultation exercise must be implemented as a matter of considerable urgency.</p>
<p>7 Any legislation that is introduced to have oversight of the shale gas industry must be fully aligned with the Astronomy Geographic Advantage (AGA) Act and any proposed activity must be cleared with the Astronomy Management Authority (AMA).</p>	<p>The HFMC or the body referred to in Recommendation 4 must liaise with AMA to ensure that before any licence is awarded the terms and conditions for such an award are fully aligned with the AGA Act and approved by AMA.</p>

Over and above all else is that the decision-making processes to proceed or not with shale gas development in the Karoo must be based on robust and peer-reviewed scientific data and facts.





1 INTRODUCTION



1.1 Background to the Study

South Africa's National Development Plan (NDP) has prioritised the need for economic growth to be closely linked to sustainable energy production, skills development and job creation. The government is looking to shale gas development in the Karoo to contribute to these objectives.

The Academy of Science of South Africa (ASSAf) was requested by the Department of Science and Technology (DST) to conduct an assessment of the technical readiness of South Africa to support the shale gas industry. ASSAf partnered with the South African Academy of Engineering (SAAE) in this study.

1.2 Study Methodology

A panel, under the chairmanship of Professor Cyril O'Connor, undertook the study. The full membership of the panel is presented in Table 1-1, and member biographies are presented in Appendix 1.

Table 1-1: Composition of the study panel

Name	Affiliation
Prof Cyril O'Connor	University of Cape Town
Mr Stephanus de Lange	University of the Free State
Prof Maarten de Wit	Nelson Mandela Metropolitan University
Mr Stefan de Nagy Kóves Hrabar	Mirlem (Pty) Limited
Prof Meagan Mauter	Carnegie Mellon University
Dr Mike Shand	Aurecon South Africa (Pty) Ltd
Mr Mthozami Xiphu	South African Oil and Gas Alliance

The study was initiated in April 2014. Where panel members lacked the relevant knowledge in key focus areas, notable experts were commissioned to undertake comprehensive assessments. The panel and commissioned experts held a three-day workshop in February 2015 to provide an opportunity for debate on the information accumulated. Thereafter, the panel met to finalise their recommendations.

The final draft report was submitted for peer review in March 2015 (the biographies of the reviewers selected and approved by the ASSAf Council appear in Appendix 2) and the ASSAf Council approved its publication at a Council Executive meeting on 11 June 2015.

1.3 Scope and Objectives of the Study

In recent years, the discovery of very large shale gas resources and the exploitation of shale gas (and shale oil) reserves in countries such as in North America have transformed the energy market. It is also common cause that South Africa is considered to possess potentially large resources of shale gas. If South Africa decides to exploit these resources, it is possible that this may be the so-called 'game changer' with respect to our energy balance in the foreseeable future. However, at the same time, it is well known that the exploitation of these key energy resources may have significant social, economic and environmental impacts and also present considerable technical challenges. Hence it is of critical importance that all these matters be analysed carefully and evaluated before exploitation of shale gas is considered.

The possibility of exploiting South Africa's shale gas deposits is of significance given the recent challenges the country has been facing in terms of energy supply. This is not to exclude the fact that shale gas also presents other downstream opportunities in terms of, for example, providing a key resource for the production of liquid fuels and chemicals through the gas-to-liquids (GTL) process, in which South Africa is a world leader, or of developing a domestic market for the use of gas as a cleaner energy resource. The market opportunity is large and diverse, but is arguably underpinned in the immediate future by the use of gas for power generation.

This report specifically addresses the technical readiness of South Africa to support a shale gas industry. The report begins with a brief overview of the basics of the technology of hydraulic fracturing and a short historical background. This is followed by an overview of the shale gas industry internationally. There is much to be gained from an understanding of the international experience. Many countries have recently carried out similar studies to the present one and it is clear that many of the challenges which South Africa is facing in this regard are also being experienced globally. This is followed by an evaluation of factors relevant to the pre-production phase, including issues related to exploration, legislation and governance, and the potential impact of such an industry on, *inter alia*, water and air quality, the Square Kilometre Array (SKA) project, and socio-economic aspects. A detailed analysis is then presented on the rationale and methodologies for baseline studies in the Karoo. Finally, post-production phase issues, such as well construction, shale gas exploitation and skills development, are considered. The report ends with a summary of key findings and a set of recommendations.

1.4 Overview

Recently, there has been considerable interest in the possibility of developing a shale gas industry in the Karoo in areas that include parts of the Eastern, Western and Northern Cape provinces of South Africa where it is generally accepted that large shale gas resources potentially exist. However, it also needs to be appreciated that there are considerable uncertainties associated with the development of a shale gas industry. These include the following:

- The quantum of shale gas in this area is still unclear with estimates ranging between 19 tcf and over 400 tcf (US EIA, 2013). None of these reserves has yet been proven.
- Shale gas exploitation requires the use of relatively large quantities of water. Given that it is unlikely that potable groundwater will be used for any such exploitation, greater clarity is needed on the availability of underground saline water, which is widely considered today to be acceptable for use in hydraulic fracturing.
- Baseline studies need to be carried out to ascertain with greater certainty the deep level (>3 km underground) geological characteristics of the area.
- Given that currently South Africa is experiencing a serious skills shortage in terms of the high-level technical competencies that would be required to implement such an industry, strategies need to be set in place to develop in the long term the skills that will be required for the sustainable development of the shale gas industry.
- International experience has highlighted the critical need to have all the necessary legislative and regulatory structures in place, as well as sufficient number of regulators with the required skills before a shale gas industry is launched.
- The implementation of a shale gas industry in an area such as the Karoo may have major socio-economic impacts on the local population and it is important to ensure that there is a full understanding of these potential impacts and that plans are developed to manage them.
- The industry will require significant infrastructural development that needs to be quantified and funded.

These uncertainties are indicative of the risks and challenges associated with the establishment of a shale gas industry in South Africa. It is also necessary to appreciate that a shale gas industry in many respects is akin to a manufacturing industry and hence requires degrees of certainty that are normally associated with similar cost-driven industries. This will require government to give attention to creating an enabling environment to encourage investment in the industry without in any way compromising on the need to ensure that all operations are fully compliant with international best practice and that the state and, particularly, local

communities, benefit from the development of this industry. This will require that all companies engaged in the shale gas industry are aware of the need to be fully compliant with all relevant legislation and regulations. It is also critical that an appropriate degree of clarity exists regarding the pricing structures that may prevail when the industry would begin to exploit the shale gas reserves. Such clarity would also be important in enabling appropriate decisions to be made when evaluating the best options to adopt in addressing the energy challenge. If shale gas is to be a significant contributor to the energy mix in South Africa then it will be important to encourage the operators, while at the same time stimulating the market. Such an exercise is obviously predicated on the need to have a clearer understanding than exists at present of the potential quantum of the known reserves.

Given the complexity of the opportunity presented for the development of a shale gas industry, a 'whole-of-government' approach is required. This will require, *inter alia*, that appropriate steps are taken to ensure that there exists a structure to facilitate and coordinate all the activities relating to the industry.

It also needs to be recognised that the lead time for the full implementation of a shale gas industry in South Africa will be, arguably, ten or more years from the time of the award of the first exploration licences. The award of a production licence, which would proceed after the satisfactory completion of the terms associated with an exploration licence, would also require the operators to have demonstrated in a defined time frame that their processes will be compliant with all the relevant legislation pertaining, *inter alia*, to well construction and drilling, water management and contribution to skills development.

It is also important to appreciate that the development of such an industry requires the state to engage proactively with all stakeholders, particularly local communities. In this context it should be recognised that there is widespread suspicion in the public domain regarding the promotion of the industry by operators with a vested interest in the industry. Thus the government has an important role to play as an 'honest broker' of key information on the short, medium and long-term ramifications of the implementation of a shale gas industry.

In summary, it is the view of the panel that before South Africa can consider itself to be technically ready to implement a shale gas industry much needs to be done to ensure that there is in place a clear legislative environment and a rigorous regulatory and monitoring structure which will ensure that operators, in using their exploration and production licences, apply best-practice technologies that are fully compliant with the rules and regulations governing the industry. The report concludes by presenting a set of recommendations which it is proposed needs to be addressed,

some urgently, such as the commencement of baseline studies, in order to ensure that South Africa does indeed become technically ready if a shale gas industry is implemented. The panel is of the view that no licences for exploration or production should be issued until the recommendations of this report have been implemented in order to ensure that an environmentally safe industry is created.



2 THE SHALE GAS DEBATE



2.1 What is Shale Gas and Where Does it Occur?

Shale is a sedimentary rock that is composed predominantly of consolidated clay-sized particles deposited as muds in low-energy environments, such as tidal flats and deep-water basins, where the fine-grained clay particles once fell out of suspension in the quiet waters. When the muds accumulate, accompanying organic matter derived from algae and the remains of plants and animals oxidises and disperses relatively rapidly. However, in reducing environments where the water lacks oxygen, such as inland seas, in stagnant lakes and wetlands, the organic debris provides the muds with decaying riches (including trapped biogenic gas) that, under elevated pressures and temperatures, eventually metamorphose to organic oil and gas (thermogenic gas) when the sediments are buried at depths of many kilometres.

Shale with an organic matter content higher than roughly 0.5% is referred to as a black shale (e.g. Trabucho-Alexandre, 2014; Bryndzia and Bransdorf, 2014). As mud turns into rock over geological time, bacteria metabolise available organic matter at shallow levels and release biogenic gas (methane - CH_4) as a by-product. If the shales are buried to only a few hundred metres deep, their biogenic CH_4 may seep into groundwater and infiltrate water wells. Aquifers in many sedimentary basins worldwide, including the Karoo, contain dissolved biogenic CH_4 .

Thermogenic gas reservoirs form when the organic matter in the mud is subjected to temperatures of between 80°C and 200°C and pressures of 1 - 3 kbar (approximately 3 - 10 km below surface), and is retained in the host as the mud simultaneously converts to an impermeable rock (shale) trapping the gas in fine unconnected pore-spaces as shale gas. Shales are thus both the source rock and the reservoir rock, i.e. gas-shales. Thermogenic CH_4 can be differentiated from biogenic CH_4 through stable isotope analysis, and when such analysis is combined with that of other mixed gases (ethane and propane), unique depth of origins of the gasses can be determined (e.g. Tilley *et al.*, 2011; Tilley and Meulenbachs, 2013).

Previously, shale was regarded only as a source rock for 'free' gas that accumulated in adjacent porous sandstone and limestone reservoirs (this is known as 'conventional' gas), and as having the impervious shale layers

that prevented the escape of gas from these more porous units. The very fine sheet-like clay mineral grains and laminated layers of shale result in a rock with permeability that is limited horizontally and extremely limited vertically. Thus, any gas trapped in shale is generally characterised as 'tight' and does not move easily within the rock except over geologic expanses of time – millions of years – unless it is artificially stimulated (e.g. fractured). Shale layers therefore function as 'strong-room' reservoirs (gas-shales) for natural gas (shale gas), often referred to as 'unconventional' gas because until some ten years ago it was not possible to extract this gas economically.

Shale gas is typically a 'dry' gas composed primarily of CH₄, but some formations produce a more fluid-rich mixture with other gases, such as ethane, butane and propane, known as 'wet' gas.

The porosity of the shale determines its value as a gas reservoir: the greater the volume of pore-space the greater the volume of gas that can be stored and thus potentially extracted. Permeability is a measure of the extent of interconnectivity between the pores and is an indication of the ease or difficulty encountered in extracting fluids from rock, or injecting fluids into rock. The higher the permeability the easier it is to produce gas or liquids from a rock. The need for artificial fracturing of shale to connect the pore spaces, and in doing so enable harvesting its gas, derives from its low permeability. Whereas sandstones for conventional gas (and oil) producing reservoirs have permeabilities in the range 0.5 to 20 millidarcies (mD), gas-shales are many orders of magnitude less permeable. Not all shales produce gas, even when stimulated through artificial fracturing, because of their ductile nature when these have a high clay-mineral content.

Favourable features for the occurrence of shale gas include:

- Fine-grained lithology (shale/siltstone/mudstone) with sufficient total organic carbon (greater than 1 - 2%).
- Shales with high porosity but low permeability.
- Thickness of gas-shale layer greater than 10 m.
- Thermal Maturity – Wet Gas window, more than 0.8 VRo (Vitrinite Reflectance), and Dry Gas window, more than 1.2 VRo.
- Moderate thermal history with less than 3.0 - 3.5 VRo.
- Moderate to low clay content (less than 40%) with very low mixed layer clays.
- Brittle composition (low Poisson's ratio and high Young's Modulus) with up to 50% quartz.
- A rock fabric (natural fractures) that enhances productivity.
- High lateral continuity of reservoir conditions.
- Organic matter that is not oxidised.
- Depth to the shale gas horizon of 1.5 km or greater.

Some 275 million years ago, the Karoo was a vast inland sea. Under its surface, organic muds that had accumulated were buried and transformed approximately 25 million years later to form oil and gas. The free gas and oil have long since leaked out, but pockets of 'tight' gas may remain preserved in tiny voids of the shale sequences (the most significant of which is known as the Whitehill Formation).

To access the 'tight' gas from the shales that are at depths between 1 500 to 5 000 m below surface, requires sophisticated drilling and extraction techniques using hydraulic fracturing (also known as 'fracking'). Shale gas extraction is a water-heavy process using extraneous chemicals. Consequently, there is much debate, globally, about the environmental impacts and safety of these technologies, and the long-term integrity of the gas wells.

The Karoo is a place of unique biodiversity, stark beauty, wide open vistas and unsurpassed night skies. Yet, the Karoo is also a place of intense poverty, with marginalised structurally unemployed people and some of the greatest chasms between the rich landowners and those who own nothing. Therein lies the dilemma for decision-makers.

2.2 How is Shale Gas Accessed?

To liberate the gas from the shales, a stimulation technique known as hydraulic fracturing (or fracking) is used to create fractures that increase permeability (fractures are open spaces and induced fractures at depth are kept open under great pressures by inserting sand grains into them). This creates a producing reservoir from which gas can flow readily to the well-head. The associated technologies have been developed primarily in the United States of America (USA).

Three aspects have revolutionised the gas industry over the last few decades. First, modern refinements in hydraulic fracturing technology make it an extremely sophisticated engineering process, computerised to emplace predetermined fracture networks into specific rock layers as thin as 1 m at up to 5 km below the surface. Injecting a pressurised fluid breaks apart rock beds; the fluid is recovered in part (depressurised) to allow gas to drain to the surface.

Second, modern drilling technology allows the drill to turn corners at depth by making the drill-hole extend from the vertical along a horizontal track whilst accurately staying within a narrow gas-rich layer at any depth. Because the horizontal portion is easily controlled, the well is able to harvest shale gas resources from a geographical area that is much larger than a single vertical well in the same shale formation. Horizontal drilling in a number of different directions reduces the number of well sites (pads) located at the surface by an order of magnitude from what it was even ten years ago.

Third, during the 1990s, the mostly-chemical fracturing gel of the past was replaced with water and now uses only minimal additives to reduce friction, corrosion and bacterial activities, increasing the extraction efficiency and potential pollution effects.

2.3 Potential Benefits of Shale Gas

Expectations of economic returns and socio-economic benefits from shale gas development in the Karoo vary considerably, but there is no doubt that if the predicted/expected volumes of shale gas are confirmed, the potential returns for South Africa and job opportunities in the Karoo could be significant and a 'game changer'. However, the predictions are based on very limited factual data from the Karoo, being based mostly on extrapolations from USA experiences. There are no reliable evidence-based predictions, given that accurate scientific data from the Karoo are lacking. What is clear, however, is that there is still a unique window of opportunity for South Africa to prepare itself for an industry that may offer significant economic benefits.

2.4 Shale Gas Licencing and the Expected Start of Exploration in South Africa

While commercial interest did not come until 2008, energy companies have anticipated the potential in the Karoo since the 1960s, when the South African National Oil and Gas Agency, Southern Oil Exploration Corporation (SOEKOR) (the exploration division of SOEKOR is now the Petroleum Oil and Gas Corporation of South Africa or PetroSA) detected potential geological gas-bearing formations in the Karoo. However, because the formations were deep underground and the prime interest at the time was for oil, commercial interests were limited and further investigations did not follow until recent times, especially when globally, the natural gas industry emerged as a significant energy resource. The first main application for exploration in the southern and potentially the most lucrative gas areas in the Karoo came in 2008 from three foreign companies: Bundu Oil and Gas, a subsidiary of the Australian Challenger Energy; the Irish Falcon Oil and Gas; and the (Royal) Dutch Shell International. Vocal opposition from civil rights and environmental organisations, farmers and landowners in the Karoo led to a government-placed moratorium on exploration in 2011. After assembling a task team to evaluate the potential costs and benefits of shale gas in South Africa, the South African government announced a plan to end the moratorium in September 2012, but at the time of publication of this report the exploration rights have yet to be approved.

New draft regulations for shale gas exploration in South Africa were published in October 2013, and a two-year extension of the moratorium for designated areas not affecting applications submitted prior to the initial moratorium of 2011, was proposed in February 2014. This has also banned

exploration that would involve hydraulic fracturing everywhere until the release of final regulations, which were expected to be completed by mid-2015. Exploration for, and production of oil and coal bed CH₄, as well as preliminary exploration for shale gas, which would include data-gathering measures, were thus permitted. As a first step to processing applications for shale gas exploration, the Petroleum Agency of South Africa (PASA) instructed the current applicants to review and augment their environmental management plans (EMPs) and resubmit them on or before 27 February 2015, with the proviso that consideration of the hydraulic fracturing process be excluded from the plans. Two of the three companies submitted EMPs, with Shell opting not to submit pending final regulations.

During the finalisation of the report the final regulations were published by the Minister of Mineral Resources in June 2015: GN 466 in *Government Gazette* No 38855 dated 3 June 2015. The effect hereof is that submitted EMPs can now be accepted as a step towards finalisation of the application process for each application for shale gas exploration.

It must be noted that there is no proven method of successfully accessing and exploiting the shale gas resource where it is currently located in the Karoo, other than hydraulic fracturing. EMPs may have to be repeated or augmented to ensure alignment with the regulations once they are published. This would then be followed by resubmission and reconsideration by PASA before the issuing of a Record of Decision on the EMP, followed by the consideration and approval of the application for the exploration right by the Minister of Mineral Resources.

2.5 Review of the Legal, Regulatory and Governance Aspects

The central issue considered here is whether South Africa is technically ready to embark on shale gas exploration and exploitation from the point of view of the various licensing, regulatory and administration requirements; in short, this section addresses governance aspects relevant to the development of such an industry.

2.5.1 Technical Regulations

The technical regulations indicate that the central institution to oversee these regulations is the so-called 'designated agency', which is currently PASA, which was designated in terms of Section 70 of the Act. The regulations include aspects that are the mandates of other government departments, while the final chapter deals with well abandonment and closure. Moreover, the nature of the required technical expertise to apply and monitor the regulations is broad-ranging, from experts on cement quality to wastewater quality treatment experts to seismologists. The regulations must also be considered in conjunction with the licence conditions as these conditions can elaborate issues not covered in the regulations.

2.5.2 Co-operative Governance (Chapter 3 of the Constitution)

2.5.2.1 Constitutional Aspects

The Constitution provides in Section 24(b)(iii) that everyone has the right to an environment that is not harmful to their health or well-being; and to have the environment protected, for the benefit of present and future generations, through reasonable legislative and other measures that secure ecologically sustainable development and use of natural resources while promoting justifiable economic and social development.

Of particular practical importance for the administration of resource extraction and environmental laws are the respective powers and functions of national, provincial and local spheres of government as contained in Chapter 3 of the Constitution.

One that is particularly relevant to environmental governance provides that:

All spheres of government and all organs of state within each sphere must –

(g) exercise their powers and perform their functions in a manner which does not encroach on the geographical, functional or institutional integrity of government in another sphere.

(S 41(1)(g) of the Constitution)

There is case law precedence to illustrate that the national government's competence to regulate mining does not supersede local government's functional competence of municipal planning. In short, the court found that the mining company not only had to comply with the Mineral and Petroleum Resources Development Act (MPRDA), it also had to comply with provincial planning laws. This was confirmed on appeal by the Constitutional Court, which held that “[i]t is proper for one sphere of government to take a decision whose implementation may not take place until consent is granted by another sphere, within whose area of jurisdiction the decision is to be executed”.

This is very significant for the three provinces in the Karoo as, in addition to the prerequisite mining, water and environmental authorisations referred to below, provincial consent to conduct shale gas-related activities will have to be obtained.

2.5.2.2 Intergovernmental Relations Framework Act

The key legislation which gives effect to the constitutional co-operative governance imperative is the Intergovernmental Relations Framework Act (Act 13 of 2005).

2.5.2.3 Spatial Planning and Land Use Management Act

The Spatial Planning and Land Use Management Act (*Act 16 of 2013*) was assented to in August 2013, and came into effect on 1 July 2015. The Act more or less retains the tone and approach of the Development Facilitation Act, but according to the Preamble is motivated by a number of factors, including the fact that “the continued existence and operation of multiple laws at national and provincial spheres of government in addition to the laws applicable in the previous homelands and self-governing territories has created fragmentation, duplication and unfair discrimination”.

The Act is administered by the Minister of Rural Development and Land Reform and includes among its objects the provision of “a uniform, effective and comprehensive system of spatial planning and land use management” in the country, and ensuring that it “promotes social and economic inclusion”, the provision of development principles and norms and standards, the provision of “sustainable and efficient use of land” and the redressing of past imbalances (Section 3).

The Act attempts to alleviate some of the difficulties with planning law by providing for municipal, provincial and national planning.

2.5.3 Mineral and Petroleum Resources Development Act

2.5.3.1 Introduction

The shale gas extraction regulations were made under the MPRDA. This is the central legislation governing the extraction and development of not only minerals but also petroleum, a distinction which is central to the architecture of the Act; Chapter 4 titled “Mineral and Environmental Regulation” being dedicated to “minerals”, while Chapter 6 headed “Petroleum Exploration and Production” applies to “petroleum” is central to this report. Section 69 of the Act makes Chapter 4, Chapter 7 and Schedule 11 applicable to Petroleum Exploration and Production with the necessary changes (or *mutatis mutandis*). Also relevant here are Chapter 3 “Administration” and Chapter 5 which establishes a Minerals and Petroleum Board.

The MPRDA includes definitions¹ of terms which are pertinent to the development of shale gas such as “mine” and “mineral”, etc.

It should be noted that “petroleum” is specifically excluded from the definition of “mineral” and is defined to mean:

“any liquid, solid hydrocarbon or combustible gas existing in a natural condition in the earth’s crust and includes any such liquid or

¹ Section 1 (Definitions).

*solid hydrocarbon or combustible gas, which gas has in any manner been returned to such natural condition, **but does not include coal, bituminous shale or other stratified deposits** from which oil can be obtained by destructive distillation of gas arising from a marsh or other surface deposit.” (own emphasis)*

Assuming that shale gas is not bituminous shale the only question which arises then is whether “shale gas” constitutes “...stratified deposits from which oil can be obtained by destructive distillation or gas arising from a marsh or other surface deposit”.

The phrase “destructive distillation” is a well-known term used to describe the process of extracting hydrocarbons from coal or gas. Hydraulic fracturing on the other hand, is simply a process for extracting naturally occurring gas which is entrapped within shales deep below the earth's surface.

Accordingly, the gas products resulting from the shale gas extraction process fall within the definition of “petroleum” as used in the MPRDA.

2.5.3.2 Three Stages in the Extractive Industry

Whatever extractive industry one is involved in, it is generally convenient to distinguish three distinct stages: the exploration phase (including reconnaissance), the production phase and the closure stage. The exploration phase is estimated to be approximately ten years, while the production phase could be up to 30 years or considerably more depending on the abundance of the resource. Thus the exploration phase gives South Africa, as opposed to many states in the USA, a unique opportunity to investigate research and conduct baseline studies. The challenge, however, will be to ensure that the exploration right makes it clear that the granting thereof will not automatically result in the issuance of a production right.

2.5.3.3 Environmental Assessment Requirements under the MPRDA and under the NEMA Regulations

The National Environmental Management Act (NEMA) was enacted as a general statute that coordinates environmental functions performed by organs of state. It also provides for “co-operative, environmental governance by establishing principles for decision-making on matters affecting the environment”. When listing activities, the Minister of Environmental Affairs must identify the competent authority responsible for granting environmental authorisation in respect of each listed activity. Section 24c prescribes that the Minister of Mineral Resources be identified as the competent authority where an activity constitutes mining or a related activity occurring that is petroleum. This means that it is only the Minister of

Mineral Resources who is competent to grant authorisations in respect of these activities. He/she must also be consulted before any activity relating to mining is listed.

The MPRDA addressed the exploration stage (Section 79), the production phase (Section 83) and the closure phase (Section 43). However, the sections were repealed in 2008 and a complex set of further amendments were put in place to establish the "one environmental system" outlined below. This was an attempt to align the environmental requirements under the mining legislation (MPRDA) with the environmental legislation (NEMA) and regulations. The 'old' provisions still apply to applications made before that date, however.

2.5.3.4 Closure Requirements under the MPRDA and NEMA Regulations

The shale gas regulations made under the MPRDA include provisions on well abandonment and closure. However, these must be read in conjunction with the relevant NEMA provisions. Section 43 of NEMA provides that:

"the holder of a prospecting right, mining right, retention permit, mining permit, ... or previous owner of works that has ceased to exist, remains responsible for any environmental liability, pollution, ecological degradation, the pumping or treatment of extraneous water, compliance to the conditions of the environmental authorisation and the management and sustainable closure thereof until the Minister [of Environmental Affairs] has issued a closure certificate in terms of this Act..."

A question which arises is whether the above comprehensively covers the decommissioning of a well. However, this is not pursued here as the question requires further technical consultation and input.

A number of further environmental provisions relevant to closure have been transferred from the MPRDA to the NEMA, including sections titled "Financial provision for remediation of environmental damage; Monitoring and performance assessment; Mine closure on environmental authorisation".

2.5.4 Administration of Mining and Petroleum Laws

2.5.4.1 Introduction

The MPRDA provides for a three-tier administration, namely:

- (a) the Minister of Mineral Resources;
- (b) the Director-General of the DMR; and

(c) Regional Managers designated for the specific regions.²

Chapter 5 of the MPRDA establishes an advisory "Minerals and Petroleum Board" whose functions include, among others, advising the Minister on the sustainable development of the nation's mineral resources.³ The Chapter also provides for the establishment of committees of the Board, including a Regional Mining Development and Environmental Committee.⁴ This Committee has been established under the MPRDA Regulations.⁵ Amongst other things, the Regional Mining Development and Environmental Committee must be consulted where an objection is lodged to the granting of a prospecting, mining or related right.⁶

2.5.4.2 Alignment of Mining and Environmental Laws and Administration

A perennial problem, particularly in relation to environmental assessment (EA) legislation introduced in 1997, is the fact that the management of the all-important environmental assessment procedure has been removed from the domain of the Department of Environmental Affairs (DEA). The recent past has however seen an attempt to realign the legislative and administrative regimes in the mining and environmental sectors to create "one environmental system" (DEA, 2014). The attempt has led to the enactment of four amending acts⁷, the purpose of which is to remove the environmental provisions (environmental management programmes, closure requirements and so on) from the MPRDA, while at the same time retaining the Minister of Minerals' control over the process. Despite these provisions empowering the Minister of Mineral Resources, the Minister of Environmental Affairs retains exclusive jurisdiction in a number of areas set out in Section 24(5) of NEMA, including the power to enact regulations relating to the environment and its management.

In June 2014, the DEA and DMR set in motion a set of amendments to their respective legislation to give effect to the so-called "one environmental system", for the regulation of mining and related activities (South African Government, 2014). This was effected from and implemented on 8 December 2014. The stated purpose is to initiate the streamlining of the licensing processes for mining, environmental authorisations and water use.

² Sect 8 of the MPRDA.

³ Sects 57 and 58(1)(a)(ii) of the MPRDA. According to *Pendlex*, this is about to be substituted.

⁴ Sect 64(1).

⁵ Sect 64(1). Reg 39.

⁶ Sect 10(2). S 10 is headed "Consultation with interested and affected parties".

⁷ The Mineral and Petroleum Resources Development Amendment Act 49 of 2008 (the 2008 MPRDA); the National Environmental Management Act Amendment Act 62 of 2008 (the 2008 NEM Amendment Act), the National Environmental Management Laws Second Amendment Act 30 of 2013 (2013 NEM Laws Second Amendment Act) and the National Environmental Management Laws Amendment Act 25 of 2014 (2014 NEM Laws Amendment Act).

2.5.5 The National Environmental Management Act and Other Environmental Legislation

2.5.5.1 NEMA

The DEA administers the framework National Environmental Management Act (NEMA) (*Act 107 of 1998*) as well as a suite of related laws dealing with waste management, air quality, biodiversity and protected areas respectively. The notion of sustainable development underpins the NEMA.

To give effect to sustainable development, the NEMA is built around a set of foundational environmental management principles emphasising that environmental management must place people and their needs at the forefront of its concern, and serve their physical, psychological, developmental, cultural and social interests equitably. This is followed by the imperative that "development must be socially, environmentally and economically sustainable", and that "sustainable development requires the consideration of all relevant factors...". There follow eight sub-principles, including the preventive principle, the 'polluter pays' principle and a number of other international law-acknowledged principles. The former is reflected in the principle "that the disturbance of ecosystems and loss of biological diversity", as well as ... "that the disturbance of the landscape and the nation's cultural heritage", are to be ". . . avoided, or . . . minimised and remedied". The precautionary principle, is reflected in the imperative "that a risk-averse and cautious approach is applied which takes into account the limits of current knowledge about the consequences of decisions and actions".

In the current context it is necessary to elaborate on one particular principle, namely the precautionary principle emanating from the further long-standing principle of prevention – the prevention or at least avoidance of adverse effects. The precautionary principle is, in essence, an extension of this idea in that it directs decision-makers not to postpone regulatory or other intervention merely on the basis that the scientific evidence linking the causal hazard chain has not been established. The NEMA includes the precautionary principle in the following terms:

"[A] risk-averse and cautious approach is applied, which takes into account the limits of current knowledge about the consequences of decisions and actions."

While the courts have pronounced on these principles as well as sustainable development, none of these have directly applied them in the mining or petroleum context. However, the principles provide limitless potential for decision-makers and the courts to develop a cohesive body of generally acceptable environmental management practices to give effect to sustainable development in the minerals and extractive sector.

Moreover, they explicitly acknowledge the interdependence of socio-economic and biophysical systems; often referred to as taking a systems approach and highlighting the need to give due consideration to social-ecological resilience. In harsh environments such as the Karoo, overlain by the anticipated effects of climate change, the resilience of these social-ecological systems – rather than the impacts of particular actions on specific components of those systems – is of paramount importance to achieving sustainable development.

The principal mechanism that gives practical effect to the above-mentioned principles is the notion of Integrated Environmental Management provided for in Chapter 5 of NEMA, in particular, the EIA framework and its accompanying EIA regulations.⁸ It is through EIA or strategic environmental assessment (SEA) that these principles are best tested and how environmental impacts are best managed (Retief, 2007).

In the South African context, the EIA regulations stipulate that the basic assessment report must include: cumulative impacts...; the degree to which the impact can be reversed; the degree to which the impact may cause irreplaceable loss of resources; and the degree to which the impact can be mitigated.⁹ However, there is no guidance on how responses to these questions which are particularly pertinent to shale gas extraction are to be used in taking decisions. The DMR which administers mining and petroleum sector activities has, since the inception of the regulatory regime for the carrying out of EA in 1997, managed to exclude itself from the DEA regulatory regime and imposed its own tailor-made “environmental management programme regime” under the MPRDA. The recent past, however, has seen the notion of “one environmental system” in which all environmental aspects are to be purportedly regulated under environmental and not MPRDA laws. However, a close reading of the amendments indicates that the DMR still retains ultimate control of the environmental assessment.

Moreover, while both the exploration as well the production phase of shale gas activities require the carrying out of an EIA, there is no legislative requirement in South Africa to conduct a SEA.

While South Africa appears committed to a sustainable future on paper, as outlined above, due care must be exercised such that the harsh reality of the country's energy security and economic needs do not override these aspirations for reasons of short-term economic development. This economic development driver has resulted in the relatively recent

⁸ R 543 (Environmental Impact Assessment regulations); R 544 (List 1); R 545 (List 2); R 546 (List 3) and R 547 (Environmental Framework regulations) came into force on 2 August 2010 in terms of R 664, R 661, R 662, R 663 and R 665 respectively in Government Gazette No 33306, 18 June 2010.

⁹ Regulation 22 (2)(i) R 543 (Environmental Impact Assessment regulations) Government Gazette No 33306, 18 June 2010.

enactment of the Infrastructure Development Act (*Act 23 of 2014*). It provides for the facilitation and co-ordination of public infrastructure development of significant economic or social importance to the country. It does so by providing for "Strategic Infrastructure Projects" that are likely to comprise relatively large-scale undertakings such as shale gas extraction. Notably absent is any reference to environmental impacts, the environmental right, the NEMA principles or integrated environmental management. While the Act acknowledges the NEMA and the need to carry out EAs, it provides for the fast tracking of applications. The reduction in the timeframes to complete an adequate EA process undermines the value of the EA process. More importantly, it may result in poor decisions that undermine the environmental management principles and the objective of 'sustainable development'. This is relevant to the need to carry out baseline studies referred to elsewhere in this report.

2.5.5.2 Other Legislation

Apart from the NEMA itself, other legislation administered by the DEA which imposes some form of licence or authorisation requirement, includes:

- the National Environmental Management: Air Quality Act (*Act 39 of 2004*), which provides for the licensing of listed activities in Chapter 5;
- the National Environmental Management: Waste Act (*Act 59 of 2008*), which among others imposes controls on "waste", "hazardous waste", "waste disposal facility" and requires the licensing of any "waste management activity" in accordance with Chapter 5 of the Act;
- the National Environmental Management: Biodiversity: Act (*Act 10 of 1998*). The shale gas operators will have to comply with the National Biodiversity Framework as well as Bioregional Plans provided for in Sections 38 and 40 respectively;
- Section 48 of the National Environmental Management: Protected Areas Act (*Act 57 of 2003*) provides for certain restrictions and consultation requirements regarding prospecting and mining activities in designated protected areas.

2.5.6 Astronomy Geographic Advantage Act

A unique form of protected area is the Square Kilometre Array (SKA) provided for by the Astronomy Geographic Advantage Act (*Act 21 of 2007*) administered by the DST. According to its long title, the Act is designed to provide for the preservation and protection of areas within South Africa that are uniquely suited for optical and radio astronomy and to provide for intergovernmental co-operation and public consultation in this regard.

The potential impact of shale gas exploitation on the SKA is dealt with elsewhere in this report.

2.5.7 National Water Act

Given the water-stressed nature of the Karoo, and the large volumes of water required for shale gas operations, a key area of concern is the water quantity and water quality aspects of water use for shale gas extraction including the potential effect on groundwater. The Department of Water and Sanitation (DWS) administers the National Water Act (NWA) (*Act 36 of 1998*). It too is underpinned by the notion of sustainable development and the unity of the Earth's hydrological cycle underlies the conceptual thinking behind the Act.

Two initial general sections are particularly pertinent to shale gas extraction: first, Section 2 entitled "Purpose of the Act" describes the underlying purpose of the legislation as: "...to ensure that the nation's water resources are protected, used, conserved, managed and controlled in ways which take into account... a number of factors; particularly pertinent to shale gas extraction are: (a) meeting the basic human needs of present and future generations;... (e) facilitating economic and social development;... and (h) reducing and preventing pollution and degradation of water resources...".¹⁰

A second introductory section states that the national government is the public trustee of the nation's water resources and that the Minister is ultimately responsible "to ensure that water is allocated equitably and used beneficially in the public interest while promoting environmental values".¹¹

The management and control of all water, which is broadly and importantly defined to include groundwater, is subject to these overall purposes. More specifically, in issuing water use licenses the responsible authority must consider all relevant factors.

Central to the regulatory regime for the envisaged shale gas operations is the water licensing regime provided for in Chapter 4 of the Act. This pivots around the 'use of water', a term which is widely defined to include a broad range of activities. Significantly, the term 'water use' also includes polluting activities.¹²

Acting in accordance with Sub-section 21(1)(e), the Minister published a notice in the *Government Gazette* during August 2013 stating that she

¹⁰ *National Water Act, S2.*

¹¹ *National Water Act, S3(2).*

¹² *National Water Act, S21 (a) to (j).*

proposed to declare “the exploration for and or production of onshore unconventional oil or gas resources and any activities incidental thereto, including but not limited to hydraulic fracturing as a controlled activity”.¹³ The significance of this is that in addition to the standard water use licence conditions, the responsible authority can add conditions “...specifying the waste treatment, pollution control, and monitoring equipment to be installed, maintained and operated; and specifying the management practices to be followed to prevent the pollution of any water resource.”¹⁴

In short, the wide-ranging definition of ‘water use’ reflects an integrated and holistic approach, recognising the unity of the hydrological cycle and ultimately that water must be used sustainably. This aspect together with the regulatory regime points to a commitment to sustainable use of South Africa's water resources at least on paper.

2.5.8 National Heritage Resources Act

In view of the rich paleontological and archaeological resources of the Karoo, a further act which has to be considered is the National Heritage Resources Act (*Act 25 of 1999*), the purpose of which is to manage the country's heritage resources. Of particular relevance to shale gas activities is Section 38 entitled Heritage Resource Management, which requires a heritage impact assessment to be carried out in certain stipulated circumstances. A number of other provisions are relevant to the shale gas enterprise, including Section 38 which deals with archaeology, palaeontology and meteorites.

2.5.9 Institutions

2.5.9.1 Petroleum Agency of South Africa (PASA)

The “Designated Authority” provision referred to in the regulations section above is Section 70 of the MPRDA. It provides that the Minister may designate an organ of State or a wholly owned and controlled agency or company belonging to the State to perform the functions referred to in Chapter 6 dealing with petroleum resources. To this end, the Minister designated the PASA accordingly in 2004. The functions of this statutory body are set out in Section 71 of the Act.

The primary roles of PASA are to act as promoter of offshore and onshore petroleum exploration, as well as being the regulator for the exploration for, and production of onshore and offshore oil and gas resources in South Africa.

¹³ *Government Gazette 36860, N 863 (23 August 2013).*

¹⁴ *National Water Act, S29(1(d)(ii)).*

2.5.9.2 PetroSA

The present day PetroSA grew out of the former parastatal SOEKOR Exploration and Production (E&P). In 2002, as part of the rationalisation of the Central Energy Fund (CEF) group, SOEKOR E&P and parts of the Strategic Fuel Fund were merged into Mossgas to form PetroSA. Currently, PetroSA owns and operates South Africa's petroleum assets on behalf of the State. The licencing function, which was historically managed by SOEKOR (Pty) Ltd and another subsidiary of CEF, were transferred to PASA in 1999, as part of the restructuring of the group.

2.5.10 Human Resources for Implementation under the Minerals (MPRDA), Environmental (NEMA) and Water (NWA) Legislation

Historically, the DMR and DEA each had their own respective environmental implementation personnel. However, the move to the "one environmental system" referred to above has resulted in an amending provision to the NEMA to make provision for the Minister of Mineral Resources to designate a new category, namely Environmental Mineral Resource Inspectors (EMRIs), who are staff of the DMR.¹⁵ Their function is essentially the same as that of an Environmental Management Inspector – as set out in Section 31G(1) of NEMA, that is to monitor and enforce compliance with the environmental legislation, and investigate non-compliance. The Minister of Mineral Resources can designate any official of the DMR as an EMRI. Significantly, the first group of EMRIs underwent training in November 2014.

Officials from DWS, the so-called Blue Scorpions, continue to enforce the NWA in terms of their powers under that Act and it appears that they will continue to do so, also with relation to the mining environment. No officials from DWS have been appointed as EMIs.

2.5.11 Summary

Given the fact that shale gas extraction encompasses the mandates and expertise of a cross section of government departments and parastatals, it is suggested that an inter-agency statutory body be established, or alternatively that the mandate of an existing body be modified, whose overall function will be to promote and facilitate the development of the onshore and offshore oil and gas industry in South Africa.

It is clear that attention will need to be given to ensure that the appropriate staff numbers and technical capacity be available to effectively carry out these two separate and crucial functions (Section 6.3).

¹⁵ S 31BB of the NEMA.

Finally, it is important to appreciate the ramifications of the precautionary principle, a fast emerging and central principle of international environmental law, recognised in South African case law, and incorporated as a principle in the NEMA.



3 **INTERNATIONAL PERSPECTIVES**



3.1 Introduction

3.1.1 Preamble

In the short space of ten years shale gas has transformed the global energy outlook completely. This new natural gas resource, located in more than 30 sedimentary basins across the continental USA, accounted for about 1% of gas production in the USA in 2000, 10% in 2011 and by 2035 that number is expected to reach around 50% (US EIA, 2014). While Canada has also experienced successful and extensive exploration for shale gas over the past five years, largely in the west of the country, the rest of the world is still at a relatively early phase of developing its shale resources. No commercial shale gas has been produced in Europe yet, but acreage acquisition has already taken place in Sweden, Germany, Poland, France, the UK and elsewhere. Some companies have conducted tests to assess likely impacts of the exploitation of shale gas. Poland is the main proponent of shale gas in Europe, and to date shale gas has been produced although initial results have been below (inflated) expectations. In China (Sichuan Basin) and Australia (Georgina Basin), extensive tests are still underway. While some encouraging results have been reported, initial flow rates in China have not lived up to (again inflated) expectations.

Whether the shale gas boom remains an exclusively North American phenomenon will undoubtedly unfold over the next ten years. Here we present a pragmatic perspective of why shale gas exploitation has been either strongly embraced or vigorously opposed in selected countries from North America, Europe, Australasia and Asia.

3.1.2 Challenges Facing Sustainable Energy Supply and Demand

In its New Policy Scenario, the International Energy Agency (IEA) has stated that world primary energy demand will increase by 36% between 2008 and 2035, from around 12 300 million tonnes of oil equivalent (mtoe) to over 16 700 mtoe, or 1.2% per year on average. The global problem we face is one of maintaining economic growth by increasing exploration and production efficiency, whilst also seeking ways to reduce negative environmental impacts. The latter has both global (i.e. greenhouse gas (GHG) emissions) and local to regional (safe exploitation and storage practices, protection

of groundwater, etc.) dimensions. The overall challenge is embodied in the term “sustainable development”, defined as development that meets present-day needs without compromising the ability of future generations to meet their needs, and “stewardship” which refers to the responsible planning and management of resources. The economic component of sustainability requires that the supply of geo-resources should be secured on a long-term basis, calling for an efficient use of available resources and a balanced mix of conventional and alternative resources (considering availability, affordability, and environmental impact). The ecological component calls for the preservation of the environment (*sensu lato*), in that the extraction of one resource (energy, raw materials) must always be planned with due consideration for other resources (potable water, soil). The key message is simple: sustainability has four attributes (Figure 3-1), all of which have to be balanced in order to reach a beneficial solution for any given nation.

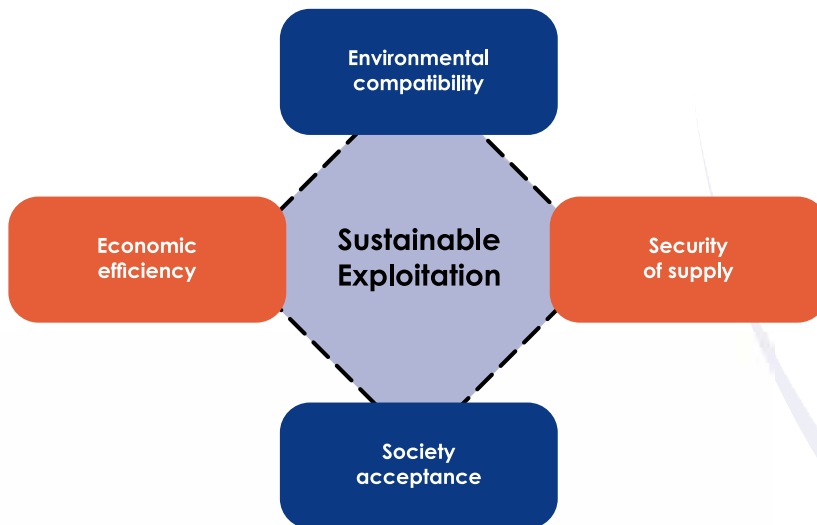


Figure 3-1: Sustainable primary energy exploitation has four elements, each of which is of crucial importance

Every nation builds its primary energy supply from a mixture of sources. South Africa's energy mix is heavily dependent on domestically mined coal. The production and use of these deposits enable South Africa to satisfy 70% of its energy demand and 90% of its electricity production utilising coal-fired power plants (US EIA, 2014). South Africa, having signed the Kyoto Protocol, strives towards reducing GHG emissions by 34% by 2020. South Africa therefore must look to increasing the contribution of low-carbon alternative energy resources, including renewables, and the cleanest burning fossil energy fuel, natural gas.

3.1.3 In a Nutshell – What is Shale Gas?

Natural gas features prominently in most national energy portfolios. Because of its (arguably) lower carbon footprint than coal and flexible availability, it is widely regarded as the most important bridge to a low-carbon energy future.

Global *in situ* shale gas resources are extremely large (Figure 3-2). In view of the volatility of oil and gas prices, and the gradual switch to renewable energies, the question arises as to the long-term viability of shale gas and shale oil production. Currently, low global oil prices and low USA gas prices are curtailing exploration activity, but not destroying the shale gas industry (*The Economist*, 2014a; Sanati, 2015).

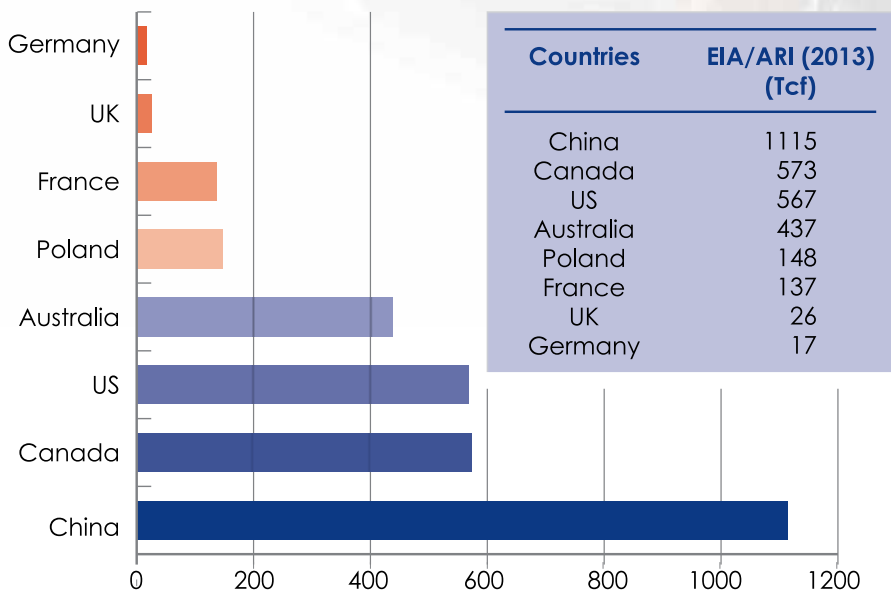


Figure 3-2: Technically recoverable resource (TRR) potential of shales in the countries under study in this report (US EIA, 2013a)

3.1.4 What are the Benefits, and What are the Risks?

Hydraulic fracturing is frequently thought to be new and risky, but the technology in its basic form, injecting fluid at high pressure to fracture the target, has been employed since 1947 on more than two million wells drilled mainly in conventional petroleum systems (gas in sandstone reservoirs within geological traps). The factory-style (many wells from a single pad or closely spaced single pads) hydraulic fracturing of shale targets via horizontal wells and using high-pressure aqueous fluid with proppants (particles to keep induced fractures open) and additives (to facilitate efficient and safe engineering operations) is a relatively recent

innovation, and has been applied to more than 70 000 wells drilled specifically into shale targets over the past ten or so years.

The question of the safety of hydraulic fracturing has been addressed by a great many scientific and governmental bodies. The Geological Survey of Germany has stated that *"from a geoscientific point of view, environmentally-friendly application of the technology is possible, as long as the law is observed, the necessary technical measures are taken and local baseline studies and pilot surveys are carried out... (plus)... hydraulic fracturing is compatible with the protection of freshwater reservoirs"* (Bundesanstalt für Geowissenschaften und Rohstoffe, 2012). Leading geoscience institutes in Germany have concluded that best practice engineering procedures, coupled with geological analysis and monitoring, are fundamental to the safe exploitation of shale gas and protection of aquifers (Hannover Declaration, 2013) and this has been recently reiterated by a number of global academies (ACOLA, 2015).

Yet, groundwater contamination by surface spillage at some drill sites and the reported leakage of gas via poorly constructed casing of the well-bore shows that shortcuts have been taken, or that accidents have occurred, in USA shale plays. The purported contamination of drinking water by the chemicals used to stabilise clays, minimise corrosion or sterilise against micro-organisms has not been demonstrated to have occurred. The same is true of aquifer contamination by water returning to the surface (flowback or produced water) after hydraulic fracturing has concluded. It is noteworthy that these wastewaters are nevertheless highly saline and must be disposed of responsibly. Injecting them into deep, voluminous and permeable geological formations is common practice, but it is contended that extremely high pumping rates may have brought about induced seismicity in the form of earth tremors and sometimes quakes in Oklahoma and elsewhere. The fact that hydraulic fracturing needs large volumes of water is also a concern, especially where the shale target formation lies beneath arid localities, or where drinking water is in short supply.

The American Association of Petroleum Geologists (Engelder, 2014) has acknowledged serious shortcomings in the development of the shale gas industry. The lack of a strong regulatory framework played a part because risks must be managed, and maximum legal clarity and predictability provided to both market operators and citizens.

The key message is that shale gas can secure primary energy supply utilising state-of-the-art technology, but it is most important that careful attention be given to ensuring that appropriate regulations for protecting the environment are in place.

3.1.5 Retaining a Balanced Perspective

It is fair to say that shale gas has acquired a negative image as far as the general public is concerned. The Dutch Geological Organisation TNO (*Toegepast Natuurwetenschappelijk Onderzoek*) has tried to encourage logical debate by producing an 'Argument Map'. Pro and contra arguments are laid head-to-head for the categories of energy, environment, safety, economy and politics so that educated decisions for or against its development domestically can be made. This Argument Map is presented in Figure 3-3.

A key element missing from these deliberations is the personal perspective. Mineral rights in the USA belong to the landowner, meaning there are financial benefits to be had for the landowner from utilisation. In Europe and South Africa, however, the mineral rights belong to the state and not the landowner. This is a key point to keep in mind.

The key message is that sound scientific evidence needs to inform the arguments for or against hydraulic fracturing. In truth, evidence alone has not determined the paths taken by the nations presented below, but this should not preclude the need for the evidence to be made widely available.

ARGUMENT MAP SHALE GAS PRODUCTION IN EU MEMBER STATES

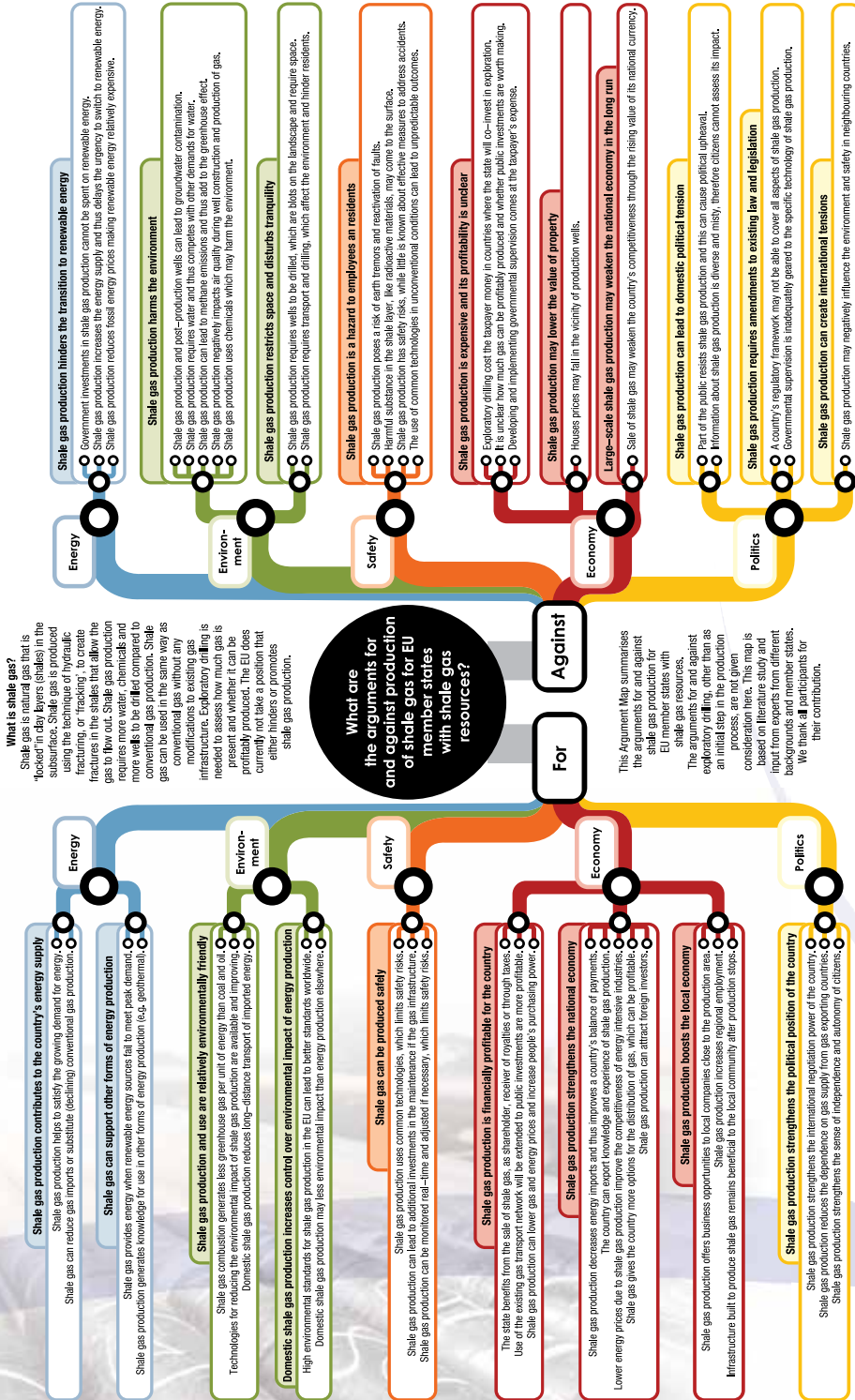


Figure 3-3: The Argument Map lays out the pros and cons of shale gas exploitation in a logical manner (www.shale-gas-information-platform.org/)

3.2 Overview of Shale Gas Development by Country

3.2.1 United States of America

Technically recoverable resources (TRR) for shale gas are estimated to be 567 tcf (US EIA, 2013a).

In the late 1970s, the USA started with the development of unconventional natural gas as a result of active government research and development programmes and private entrepreneurship. Technological innovations and key technologies such as horizontal drilling, 3-D seismic imaging, and fracturing technology were developed in the 1980s and the 1990s. The progress of the technology of microseismic frack monitoring in the early 2000s had a huge impact on shale gas development (Zhongmin and Krupnick, 2013). The development of the shale gas industry over this period remained essentially unnoticed by the general public.

The favourable geological conditions in the USA, the private land and mineral rights ownership system, an existing and extensive pipeline infrastructure, and high natural gas prices in the 2000s, all contributed to a rising unconventional oil and gas industry (Zhongmin and Krupnick, 2013). The unconventional oil and gas industry created around 2.1 million direct and indirect jobs in this sector in 2012 (IHS, 2013).

With the rising success of exploitation of shale gas and increasing attention by the media, the public was alerted to the environmental aspects of shale gas production. Stronger environmental regulations have been introduced (Considine *et al.*, 2013).

The key message here is to use the wealth of information from the USA – how to and how not to – as a basis for planning shale gas exploitation in other countries. Only in the USA is there a statistically valid database upon which to evaluate technical successes and failures.

3.2.2 European Union

The European Union (EU) stipulates that exploration rights should be the same across Europe. The EU has directives in place concerning drinking water, groundwater, dangerous substances in water, air quality, noise from outdoor equipment, habitats and wild birds, all aspects which are part of planning and regulating shale gas exploitation (EU, 2015). It is up to member states to apply the directives.

Member states continue to take very different positions on shale gas, driven by their own political agendas, and shaped by their individual energy policies and energy security concerns. Environmental issues continue to dominate headlines and influence the debate.

3.2.3 United Kingdom

Gas-in-place has been estimated to lie in the range of 822 - 2281 tcf (Gov. UK, 2013). The TRR for shale gas are estimated to be 26 tcf according to US EIA (2013a).

One third of Britain's energy mix is met by natural gas and the resource is likely to be important in the future as old coal and nuclear power stations shut down. The UK government strongly supports the development and exploration of shale gas because of greater energy security, increased tax revenue, job creation and contribution to economic growth (DECC, 2013a).

Hydraulic fracturing has been conducted in the UK for many decades in approximately 200 wells without any negative environmental impact (The Royal Society and The Royal Academy of Engineering, 2012). The Royal Society Report (2012) concluded that *"The health, safety and environmental risks associated with hydraulic fracturing (often termed 'fracking') as a means to extract shale gas can be managed effectively in the UK as long as operational best practices are implemented and enforced through regulation"*.

The UK government provides incentives to communities who host energy sites, either nuclear energy or unconventional gas and oil (Gov UK, 2014). National agencies, as well as industry, strongly support research institutions to bring scientific knowledge to the public's attention.

The key message is that the UK government has learned from the USA situation that developing shale gas, seen as a key to national security and well-being, must be accompanied by strict operational regulations, using baseline monitoring as a means of enforcement, and providing financial benefits for all stakeholders.

3.2.4 Poland

The TRR for shale gas are estimated to be 148 tcf according to US EIA (2013a). The Polish National Geological Service (PGI, 2012) suggested 12 - 27 tcf (possibly up to 67 tcf), while a resource assessment by the US Geological Survey (Gaultier *et al.*, 2012) suggested 1.3 tcf (using "estimated ultimate recovery").

Poland's energy mix relies heavily on indigenous coal (55%; IEA, 2011). Energy security is a high policy priority in Poland because 60% of its gas demand in 2013 was provided by Russia (*The Economist*, 2014a). Alongside other supply projects, shale gas would allow the diversification of Poland's energy sources, hence, shale gas production is supported by all the main Polish political parties (Rutkowski, 2013).

However, despite a favourable socio-political climate supporting exploration, the shale gas industry has not grown rapidly; a lack of appropriate regulations and laws (a new hydrocarbon law, two years in the making, was passed in August 2014), bureaucratic tangles and an unfriendly investment climate (e.g. waiting 18 months for permission to start drilling) have contributed to the situation. The country is to introduce another shale gas regulation in 2015 to attract and accelerate investments.

Shale gas development in Poland has strong public support. A poll conducted in September 2011 resulted in 73% of the respondents supporting shale gas extraction in Poland. There has been active dialogue with stakeholders who are involved in regular debates on the various and sometimes controversial aspects of shale gas exploration and production. Furthermore, scientific research is actively supported by the government.

The key message is that appropriate regulations need to be provided before exploration gets underway in order to provide a consistent and robust framework for developing the resource.

3.2.5 Germany

The TRR for shale gas are estimated to be 17 tcf (US EIA, 2013a) and 25 - 81 tcf according to the German Federal Institute for Geosciences and Natural Resources (*Bundesanstalt für Geowissenschaften und Rohstoffe (BGR)*, 2012).

Germany imports around 70% of its energy resources. Only one quarter of Germany's energy supply is produced domestically (including renewable energy). The plan to shut down all nuclear power plants by 2022 in the wake of the Fukushima tragedy has had dramatic consequences for Germany's energy mix, in that the energy gap has to be filled. Natural gas could replace part of the energy from nuclear power plants. However, Germany has several very active citizens' initiatives and environmental organisations opposing not only shale gas but also CO₂ storage, geothermal energy, nuclear energy and wind turbines. The federal government has no clear statement on shale gas exploration and production in Germany. A new bill on hydraulic fracturing regulation is awaited in the cabinet; the draft stated that a science-backed pilot plant is needed to investigate the impacts on the environment.

Germany has a longstanding and successful tradition in oil and gas development. Hydraulic fracturing has been used there 300 times in vertical wells since the 1960s, and three times in horizontal wells with shale targets. Numerous reports have been issued by federal and state bodies on shale gas. The BGR (2012) report came to the conclusion that shale gas extraction is safe if best practices are used. The *Staatlichen Geologischen Dienste der Deutschen Bundesländer (SGD)* and BGR (2013) together

released a similar statement. The environmental groups are negative towards shale gas. Recently, the environmental ministry stated that the team of consultants it had commissioned had condemned shale gas, a point which the consultants said was contrary to their recommendations.

The key message is that Germany will continue to debate shale gas for a long time to come. The country has no clear policy on shale gas, and is willing to rely on imported oil and gas to supplement its coal-dominated energy mix, while being also a proponent of renewable energy. A monitoring programme for a shale gas test well in Germany is foreseen.

3.2.6 France

The TRR for shale gas are estimated to be 137 tcf (US EIA, 2013a). In France, shale gas activity was suspended in July 2011, with a ban on the exploration and exploitation of hydrocarbons by hydraulic fracturing and the cancellation of exploration permits which had been granted. Environmental concerns were submitted as the reason for the ban.

Despite politicians, experts and industry continuing to debate the merits of shale gas and a number of pro-shale reports (including reports produced by the French Parliamentary Office for Scientific and Technological Choices and the French Academy of Sciences), France is no further forward in promoting its shale gas potential.

The key message is that France has extensive shale gas and especially shale oil in-place resources but their extractability is unknown. Political lobbying was effective in stopping shale gas development early on.

3.2.7 Canada

Canada is the third largest producer and second largest exporter of natural gas in the world, and next to the USA the second only major producer of commercially viable natural gas from shale formations. At a rate of 5 tcf/year, shale gas accounted for 15% of Canada's total natural gas production in 2012 (Energy and Mines Ministers' Conference, 2013; US EIA, 2013b). Existing estimates of total shale gas resources in Canada are in the order of 4 995 tcf, of which 343 - 819 tcf are 'marketable' resources, deemed technically and economically recoverable under current conditions (Chong and Simikian, 2014).

Considerable public concern has been expressed about the potential negative environmental, seismic and health-related impacts of hydraulic fracturing. Questions also remain in respect of the economic viability of projects, particularly if economic benefits outweigh the environmental costs. Environmental monitoring programmes are considered essential to supply credible, science-based information to develop and apply regulations (Council of Canadian Academies, 2014).

The key message is that transparent and credible monitoring of environmental impacts are required to build public confidence and achieve social acceptance, particularly in the exploitation of shale gas in areas unaccustomed to natural resource exploitation.

3.2.8 Australia

In the years prior to 2010, coal-seam gas production had already transformed Australia's energy market and moved mining activities closer to more densely populated areas. Therefore, public awareness had already triggered scepticism over hydraulic fracturing technologies and environmental risks, particularly the contamination of groundwater reservoirs and the drawdown of aquifers.

There is currently limited commercial production of Australia's recoverable shale gas resources which amount to 396 tcf (US EIA, 2013b). The production of shale gas could contribute significantly to the Australian energy economy, especially the liquefied natural gas (LNG) export market. Economic viability remains limited due to relatively high costs of exploitation techniques and absence of infrastructure at remote production sites (CSIRO, 2014).

The Australian Council of Learned Academies (ACOLA) has analysed the situation in detail (ACOLA, 2013). One of their conclusions was that *"research into Australia's deep sedimentary basins and related landscapes, water resources and ecosystems, and how they can be monitored, will be essential to ensure that any shale gas production is effectively managed and the impacts minimised"*.

The key message is that the sustainability principles apply to largely unpopulated regions, as well as highly populated ones; missing infrastructure (pipelines and water availability) in remote locations is a particularly important issue.

3.2.9 China

China's shale gas resources occur in several large basins spread across the country and are the largest known shale gas resources in the world, currently estimated at 1 115 tcf (US EIA, 2013b). A top-down mandate to develop shale gas is in place in China. The development of these shale gas resources is proving difficult and more expensive than those in the USA because the geology is rather complex and the shale targets deeper than some of the traditional USA shale plays, and well spacing and stimulation strategies are not yet fully harmonised with those geological conditions. Nevertheless, the Chinese government is providing incentives for shale gas production and has an ambitious target of reaching an annual shale gas production rate of 2.8 tcf by 2020. A five-year shale gas development

plan commits to providing production incentives with subsidies, waivers of financial controls and to the defining of shale gas industry standards. An EIA is mandatory and must be filed with national and local regulators and be approved in advance of application.

Due to limited experience of producing unconventional gas, China is keen to obtain, advance and improve its own shale gas technology by acquiring overseas assets and technology. After the introduction of a dedicated Shale Gas Industrial Policy in October 2013, however, technological hurdles still remain. Unsurprisingly at this stage, shale gas is produced at prices that are more than double those of the biggest projects in the USA. Progress may generally be constrained by the need for adequate infrastructure and the scarcity of and competition for water resources. China may also face regulatory hurdles, with an imperfect policy regime and fragmented administrative responsibility for the natural gas industry. According to *The Economist* (2014b), China has drastically reduced its ambitions to be a large shale gas producer.

The key message is that translating its vast shale gas potential into produced gas depends on the local geological conditions; extensive time and effort will also be required to build the necessary infrastructure, institutions, and regulations and standards.

3.3 Key Lessons for South Africa

South Africa urgently needs to assess its producible shale gas potential (TRR) because the security of domestic energy supply is of fundamental importance:

- South Africa must commit to a balanced long-term shale gas exploitation strategy based upon all of the four elements of sustainability, namely, security of supply, efficiency of extraction, environmental protection and societal communication.
- South Africa must learn from and build upon the shale gas and shale oil experiences in the USA, Europe, Asia and Australia, fully utilising the wealth of published evidence made available by eminent scientific bodies, and should take careful note that negative media coverage essentially stopped European shale gas development in its tracks for years.
- South Africa must commit to learning-by-doing because shale gas potential is never realised overnight; unrealistic public expectation has hit both Poland and China very hard.

- Following the examples of the UK, Germany, Poland, Canada and Australia, South Africa must conduct its own baseline studies in order to facilitate the unambiguous evaluation of environmental impingement during shale gas extraction by industry.
- South Africa must expand its interaction and collaboration with the world's leading professional and academic institutions to facilitate knowledge transfer, establish state-of-the-art working protocols and conduct regional, as well as site-specific environmental monitoring.



4 EVALUATION OF SOUTH AFRICA'S TECHNICAL READINESS TO SUPPORT A SHALE GAS INDUSTRY

– FACTORS TO BE CONSIDERED IN THE PRE-PRODUCTION PHASE



An evaluation of South Africa's technical readiness to support a shale gas industry needs to address two separate but related sets of issues. The first of these concern matters of critical importance which must be addressed during the pre-production phase. A range of such matters are addressed in this section and relate to the following:

- Exploration challenges which include the key question of quantifying the reserves of gas available.
- The need to ensure that an appropriate licensing, regulatory and administration system is in place, with a view to ensuring compliance by any operator with current best practice.
- The potential environmental impact of a shale gas industry in regard to issues such as:
 - water availability and quality, air quality, etc.;
 - the Square Kilometre Array (SKA) project;
 - the socio-economic challenges resulting from the implementation of a shale gas industry;
 - fragmentation of iconic landscapes.

4.1 Exploration to evaluate the Shale Gas Potential of the Karoo

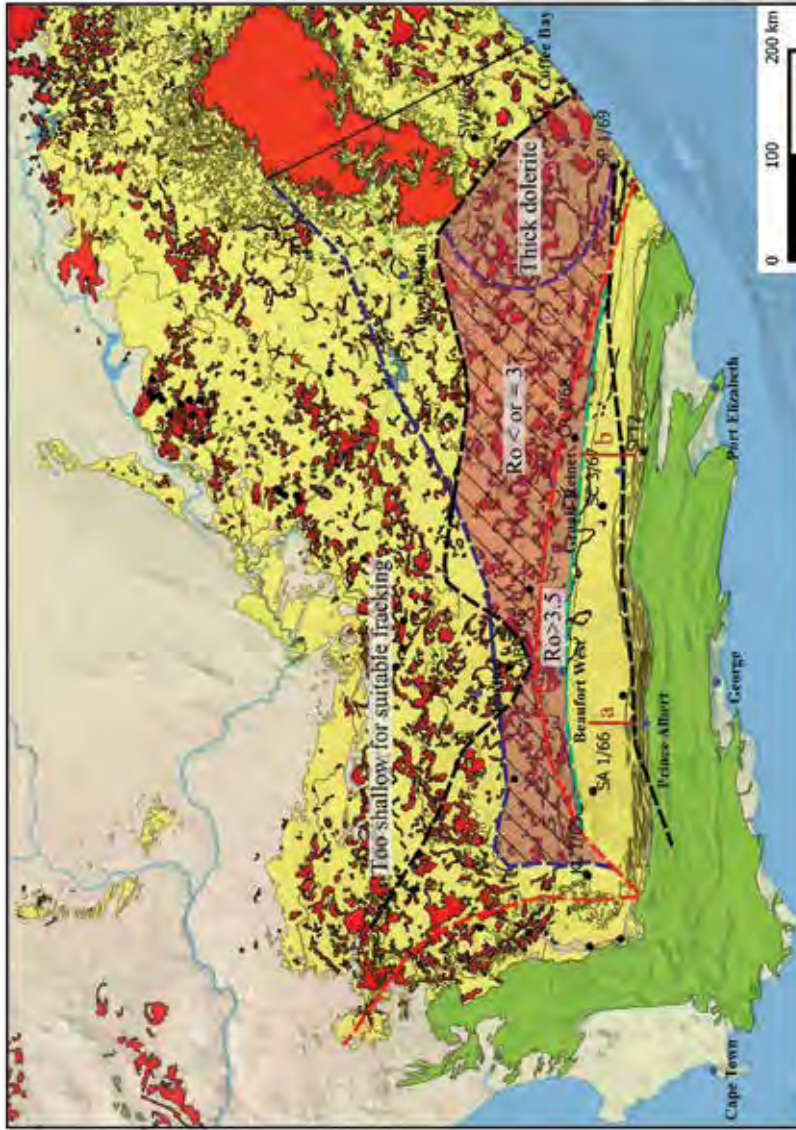
This section describes the main steps toward evaluating the shale gas potential of the Karoo through exploration, drilling and testing the potential to extract gas resources using hydraulic fracturing at selected favourable areas ('sweet spots') in the Karoo.

4.1.1 Shale Gases and Gas-Shales

From past and ongoing research, it appears that the favourable features for the occurrence of shale gas (Section 2.1) are all present in at least some regions of the southern Karoo Basin (e.g. Decker and Marot, 2012; Geel, 2014, Geel *et al.*, 2013; 2015; Chere, 2015).

Prospective gas-shales are found in many sedimentary basins like the Karoo. Gas-shale sequences can range in thickness from a few metres to hundreds of metres, though the most prospective intervals may be just a few tens of metres thick. The sequences can be laterally very extensive, underlying many thousands of square kilometres, or of more limited extent.

Some basins are far more prospective than others, depending on their structural and thermal histories. If basins have been folded or faulted, as they have been along the Cape Fold Mountains flanking the southern and western margins of the Karoo, their hydrocarbons may have been naturally 'squeezed out' and their shales are less likely to retain their original volumes of shale gas. If they have been tectonically buried and/or subjected to excessive temperatures and pressures, then they may be 'overcooked' and hydrocarbons may have broken down and become 'over-mature', as is also the case along the southern margin of the Karoo Basin, where maximum temperatures between 400 and 570°C indicate over-maturity. On the other hand, if a basin has not been heated to any extent and has always been kept at shallow depths, then it is likely that thermogenic gas (or oil) would never have been generated from the organic materials, which instead may also have oxidised, as may be the case along the peripheral western and northern margins of the Karoo Basin (Figure 4-1). Therefore, to have a shale-bearing basin rich in shale gas requires both the right depositional and post-depositional conditions. These conditions are met only in limited areas of the central and eastern sections of the southern Karoo Basin (Figure 4-1).



- Legend**
- Cape Supergroup
 - Karoo Volcanics
 - Karoo Supergroup
 - Boreholes
 - Towns
 - Conservative prospective area R>3%, excluding thickest dolerite package
 - Prospective shale gas area R>3.5% including thickest dolerite package
 - 1500m Whitehill Fm. depth
 - 30m Whitehill Fm. thickness
 - Vitrinite reflectance R>3%
 - Vitrinite reflectance R>3.5%
 - Thickest dolerite
 - Pinch out of Prince Albert and Whitehill Formation
 - Cross sectional profiles a & b

Figure 4-1: Simplified geology and shale gas parameters of the Karoo, highlighting the areal extent most favourable to explore for shale gas (brown area; approximately 79 - 92 000 km²).

The area (marked by brown shading) is delineated to the south by a green line just north of Beaufort West and Graaff-Reinet and on towards East London (according to vitrinite reflectance data, $RO > 3.5$). The northern extent is delineated by the 30 m isopach of the Whitehill Formation (black dashed line), while the eastern extent, just south of Aliwal North, by the thickest dolerite intrusions in the Karoo Basin (east of purple broken line). (Modified from Geel *et al.*, 2015)

If the quantity of gas in a regional gas-shale is poorly known then it is classed as a 'resource', whereas if it is known with great confidence then the quantity of gas in the reservoir is referred to as a 'reserve'. Presently, Karoo gas-shales are a resource. Combined with the confidence with which the quantity of gas in a shale-reservoir can be determined, the cost of its extraction would determine whether the quantity of gas in a field is an 'economic reserve'. This is related to knowledge as to whether stimulation can create permeability to allow sufficient gas to flow from the rock. This can currently be done only by hydraulic fracturing (fracking) the rock to create an artificial gas reservoir composed of fine fractures. A favourable stress field and the presence of brittle structures facilitate both the degree and the control of the hydraulic fracturing and the subsequent extraction of the shale gas.

There are a considerable number of estimates of the potential Karoo shale gas resources, but all have a high degree of uncertainty attached to them. There is presently very limited knowledge about the detailed 3-D shape of the Karoo Basin and its gas-shales, hence the very large range of estimates of potential shale gas resource between roughly 10 and 500 tcf (52 tcf = 1 metric Giga (10⁹) tonne of CH₄), with a probabilistic range between approximately 14 and 172 tcf and a median of approximately 50 tcf (e.g. Decker and Marot, 2012). This aligns with the estimate of 72.5 tcf by Cole (2014). Reliable economic reserve figures for Karoo shale gas are not available, largely because there has been little or no exploration or drilling in the Karoo since the exploration for oil in the southern Karoo in the mid-1960s by SOEKOR. This early exploration phase was terminated when no oil was found. It was realised that this was related to overheating (over-maturity) of the oil, leaving only indications of gas for which, at the time, there was no interest.

With reference to Figure 4-1, and using an average thickness of 30 m for the Whitehill Formation, a porosity value of 1.57%, a gas recovery value of 30% and a 50% success factor (Decker and Marot, 2012; J. Decker, pers. com. 2014), the potential recoverable reserves probably amount to at least 19 - 23 tcf of available free gas (Geel *et al.*, 2015). This estimate does not include vast volumes of gas lost to the atmosphere during emplacement of the Karoo dolerite sills, especially in the north-west region (e.g. Svenson *et al.*, 2006, 2007; Aarnes *et al.*, 2010, 2011; Maré *et al.*, 2014); nor the adsorbed gas or micro-porosity of the gas-shales, which would

result in a higher estimate of gas present in the Whitehill Formation. Cole (2014) similarly calculated a possible resource of 18.5 tcf for the Whitehill Formation, based however on a smaller prospective area ($RO < 3.5$) and assuming dolerite intrusions in less than 20% of the succession. At any rate, gas-shales in the north-west of this map (Figure 4-1) are unlikely to be exploited because they are too thin and/or too shallow and may thus risk contamination of groundwater and wells with slickwater and/or deep saline water. It will be imperative for the efficient evaluation of this resource to narrow these estimates down to more reliable/robust numbers. Moreover, there are likely 'sweet spots' to be found that will determine the initial exploitation risks.

Following required EIA projects that may last up to two years depending on national requirements, extensive exploration programmes to evaluate the potential of its gas-shales will need to be carried out in several stages using different techniques that should overlap in time and space across the Karoo over the next three to five years. To achieve this, a two-phased exploration programme will need to be undertaken, including a late hydraulic fracturing phase at limited sites. It is likely that most of this will be carried out by international companies. However, the training of competent local scientific and technical expertise is essential for independent evaluation and monitoring of the findings.

To enable imaging of shale gas reservoirs at depths required for resource evaluation, deep geophysical probing techniques are required. Presently there is insufficient equipment and expertise in South African geoscience institutions to undertake this type of research exploration holistically. Moreover, such exploration surveys are expensive and small exploration companies may choose initially to rely only on analyses of old cores and well-data.

4.1.2 Towards a Rigorous Scientific Exploration Programme for Gas-Shales in the Karoo

The first stage of exploration involves scanning the subsurface geology using geophysical methods, mainly ground-based seismic, electrical, magnetic and gravity surveys, complemented with analyses of archived cores retrieved from a number of deep wells drilled in the 1960s. Next, a few new wells must be drilled and rock-cores collected for analysis, mostly from the geological strata where shale gas resources are expected. Geophysical measurement tools must be run down these holes to obtain additional insights into the geology, geochemistry, hydrogeology, porosity, permeability and other properties of the gas-shales at depths beyond approximately 1.5 km. Unless they are to be used later for micro-seismic monitoring, these exploration wells should be sealed with cement at the surface after the geophysical logging is completed. In shale gas plays, this exploration phase is relatively short (three to five years) and

focused on identifying the 'sweet spots'. Last, a number of wells must be constructed to enable multi-stage exploratory hydraulic fracturing to verify that gas can be efficiently and safely extracted, ahead of further potential development. This entire programme will take a minimum of between five and ten years to complete.

4.1.2.1 Exploration Phase I: Determining the Depth, Thickness and Physico-Chemistry of the Gas-Shale Sequence(s)

The main questions to be addressed in the early exploration phase are related to determining the precise depth variations of the potential gas-bearing shale sequences. It is well-understood that exploitation of the gas by means of hydraulic fracturing technology would be irresponsible at depths less than roughly 500 m below the surface, since this would entail potentially harvesting the gas within the depth of the natural potable, meteoric water-derived reservoirs of the Karoo. In addition, lithostatic pressures (rock overburden) above even 1 - 1.5 km below the surface may not be sufficient to eliminate induced connectivity between the hydraulically stimulated shale gas reservoirs and the shallow water reservoirs, because fractures generated during hydraulic fracturing may extend upwards from the shale reservoir by up to 300 - 600 m, albeit generally much less, especially at shallow fracking levels (Maxwell, 2011; Fisher, 2014; Cai and Ofterdinger, 2014). Therefore, those regions where gas-shales occur at less than 1 - 1.5 km depth below surface, and even if rich, should be avoided, at least until fracking and casing technologies improve. This eliminates a substantial part of the Karoo Basin for initial exploitation targets, including regions surrounding the Southern African Large Telescope (SALT) at Sutherland and the SKA (Figure 4-1) (Refer to Section 4.4).

Early phases of the exploration studies will focus also on trying to locate deep 'sweet spots' of gas-shales from which substantial gas may be extracted. There is general agreement that the most probable shale sequence of interest is the Whitehill Formation of the Lower Ecca Group, found 2 - 5 km below surface. Recent analyses on cores from new shallow and old deep-drill-holes have characterised the general physics and chemistry of this and adjacent layers (Geel, 2014; Geel *et al.*, 2013, 2015; Black, 2015; Chere, 2015). The total organic content (TOC) of this sequence averages 4.5%, and has a high porosity (1.3 - 3%). This fulfils the prerequisite for good potential gas-bearing shale. However, it must be borne in mind that many early analyses (e.g. vitrinite reflectance), especially in the southern Karoo, indicate that the rocks have been over-matured (e.g. >4%VRo).

The shales in all examined cores have a high quartz content which gives them sufficient brittleness required for hydraulic fracturing. The shales of this particular sequence are the main potential source of extractable gas in the Karoo Basin. Both underlying and overlying sequences (Prince Albert

and Collingham Formations, respectively) are in places also potential reservoirs but have lower TOC and both these sequences were formed under greater oxidising conditions. Interestingly, whilst the Collingham sequence has low levels of TOC (<1%), it has very low porosities (0.35 - 2.2%; average 0.4%), and is therefore potentially an excellent cap-rock that is dense and tight enough to prevent gas and other fluids (e.g. slickwater and/or saline water) escaping from the Whitehill Formation (or below) into the overlying Karoo sandstones that have greater permeability (Black, 2015).

In summary, the porosity and permeability of the Karoo gas-shales is conducive to storage of unconventional thermogenic gas. The physics of at least some of the shales is favourable for hydraulic fracturing and extracting the tight gas from them. The gas is thus potentially recoverable; and the shale appears thick and widespread enough to host potentially significant shale gas reservoirs. Beyond that, very little is known about the shale's regional thermal history and geochemical variability, for which deep drilling will be needed to retrieve fresh samples of the shale at depths and locations based on the geophysical techniques mentioned above. At least 10 to 20 such holes will need to be completed to enable more robust risk and benefit analyses of the economic potential of the Karoo gas-shales. Drilling technology exists in South Africa to complete these tasks, but follow up chemical and physical laboratory analyses of retrieved cores will need to be carried out, at least in part, outside South Africa due to the current lack of (expensive) local equipment and expertise.

Two prime objectives of the exploration phase will be to locate 'sweet spots' and to determine the precise gas content and geologic parameters of the host rocks and then to determine the depth and thickness variations of dolerite sills that have intruded the Karoo sequences, especially above the great escarpment.

For both, two main remote geophysical sensing techniques must be employed to map subsurface geology and structures. These are:

- Seismic Reflection Surveys, using slow-moving trucks with vibrators and/or inserting small shallow explosives as controlled seismic sources. New hardware and software development in seismic technologies using passive noise may in future replace the need for trucks and induced seismic sources, and its deployment should be encouraged in the environmentally sensitive Karoo.
- Electrical/Magnetotelluric (MT) Surveys, using manually-emplaced sensors and natural electrical sources.

These techniques should be complemented with selected high-resolution magnetic and non-intrusive gravity surveys, and then followed by deep

drilling at selected sites. The gravity and magnetic surveys are ideally deployed from low-speed aircraft flying at altitudes of 20 - 80 m above ground. The payloads are different depending on the technique, with gravity using a gravimeter that measures small variations in the local gravity field, and the magnetic technique using a sensor that responds to small variations in the magnetic field. Airborne gravity is particularly useful for lithological diagnostics and subsurface mapping of joints and fractures, while airborne magnetics maps near-surface structures.

Ground seismic surveys will range from two-dimensional (2-D) regional sections along selected transects across the southern Karoo Basin (more than 100 km in length) to more detailed 3-D imaging of the various rock sequences and tectonic structures that will help identify the geometry of the shale-bearing horizons and deep-water reservoirs across small regions. The latter are mostly saline in Karoo rocks at depths of greater than 1.5 km, and will thus be detectable using the electrical and magnetotelluric surveys. A special requirement will be to image the shape and thickness of dolerite sills above the escarpment, which may prove to be especially challenging. This exploration phase is expected to take a minimum of up to two to three years to complete.

Deep drilling at sites selected on the basis of results of the above-mentioned geophysics experiments, and continued drilling thereof, will have to be undertaken because the geophysical data need to be verified by down-hole experiments and laboratory studies on retrieved cores that, in turn, will provide 'anchor points' to correlate and link to the seismic and magnetotelluric survey results. Only at the deep drill sites will there be precise knowledge about the depth and thickness, as well as the chemical and physical properties of the gas-shale and other geologic horizons. Thickness variations of the Whitehill horizon (ranging between 10 and 80 m, but typically in the range of 40 - 60 m) bear on the costs and technical ability to harvest gas efficiently. Ideally, a second deep (3-D) assessment, including down-hole experiments, should be undertaken at the end of Exploration Phase I.

4.1.2.2 Exploration Phase II: Hydraulic Fracturing to Test the Harvest Potential of Karoo Shale Gas

Hydraulic fracturing will need to be completed in the Karoo at selected sites based on the early exploration programme to test whether or not the gas can be liberated effectively and extracted safely at surface. Shale gas extraction can be evaluated by drilling and fracturing more than one deep horizontal test well from a single well pad (commonly 4 - 12; Zoback and Arent, 2014). This will likely be repeated at three to five selected locations to enable statistically reliable estimates of the Karoo reserves and to assess, with confidence, the potential risks associated with harvesting the gas.

4.1.2.3 Hydraulic Fracturing Potential in the Karoo

Hydraulic fracturing is applicable, in general, to South Africa geological conditions. Except for the dolerite intrusions, the general geology of the Karoo is very similar to that of the Marcellus Basin in the USA, in which there are significant shale gas reserves. Components of shale gas extraction-testing comprise well-drilling, well-completion, hydraulic fracture stimulation and production, and real-time sensing technology to monitor and minimise risks. Large quantities of water (possibly saline water) used for hydraulic fracturing will need to be extracted from surface and/or groundwater resources. For the relatively dry Karoo this will create a significant challenge.

Whilst there appear to be no insurmountable technology barriers relating to shale gas production from Karoo gas-shales, there will be a need to adapt to particular geological features, such as:

- Local high, near-surface paleo-heat anomalies (approximately 280°C) in parts of the upper sequences in the central Karoo (Duane *et al.*, 1989; Duane and Brown, 1992; Brown *et al.*, 1994; Egle *et al.*, 1996).
- The large-scale presence of igneous rocks intruded into the Karoo sequences at temperatures greater than 1 000°C about 180 million years ago.
- The ubiquitous vertical and horizontal joint systems in the rock formations throughout southern Africa (e.g. Muedi, 2014); and the presence of possible subsurface 'ghost' fault systems beneath the Karoo Basin (e.g. Tankard *et al.*, 2009; 2011; Lindeque *et al.*, 2007; 2011; Smit *et al.*, 2015). Major local dormant faults could potentially be activated during fluid injections, especially in deep basement environments (e.g. Hornbach *et al.*, 2015).

In addition, variations of *in situ* stress fields may require modified hydraulic fracking techniques in some parts of the Karoo. Thus it is not yet clear if and how the extent to which USA-developed technical success resulting from the optimal combination of horizontal drilling of deep gas-shale reservoirs and multi-stage transverse vertical fracturing will apply directly to highly jointed and faulted Karoo rocks, especially in regions affected by the dolerite intrusions.

Whilst hydraulic fracturing operations induce minute earthquakes, minor earthquakes that have been felt by the public (≤ 3.5 on the Richter scale) have been caused not by the hydraulic fracturing itself, but by wastewater re-injection and water extraction (e.g. Hornbach *et al.*, 2015). Most experts judge the risk of hydraulic fracturing causing earthquakes to be low (e.g. Royal Society and Royal Academy of Engineering, 2012; Council of Canadian Academies, 2014; National Academy of Engineering, USA,

2014). Despite such scientific predictions, new local and regional rock mechanical studies and micro-seismic analyses must be undertaken before hydraulic fracturing can proceed within a predetermined risk-envelope. Thereafter, micro-seismic monitoring during operations can diminish this risk further (e.g. Bakken Research Consortium, 2008; Hornbach *et al.*, 2015). The risk by injection of waste fluids is greater but still low, and can be minimised through careful site selection, monitoring and management (e.g. Walsh III and Zoback, 2015; Walters *et al.*, 2015; Guglielmi *et al.*, 2015).

Finally, shale is not homogeneous and can vary greatly in mineralogical composition, geochemistry, and geo-mechanical behaviour, even over short distances. Thus, every type of shale is different and well-completion technology used to extract the gas must adapt to these variations. Because organic matter tends to adsorb thorium and uranium ions that may be moving through the deep-water flux system, gas-shales often have natural background radioactivity that is higher than that of other strata, and which may be extracted in the flowback water.

4.1.2.4 Hydraulic Fracturing Techniques and Requirements

Shale gas extraction requires the combination of brute force and sophisticated technology. Material requirements are:

- Large volumes of water, chemicals and sand (slickwater).
- Land for well pads and ancillary facilities.
- Energy to power the drill rigs, pumps, and trucks.
- Infrastructure to gain access to sites.
- Capacity to contain and treat return fluids (production and flowback water).
- High-quality cement and steel to ensure well integrity.

Well integrity refers not to the ability of the steel casing to maintain internal pressure, but to the capability of the well to prevent leakage of gas and other fluids upward into the fresh groundwater reservoirs, and the atmosphere. Thus, cement and steel casing used for the well must be of high quality. In future, plastic lining inside such casing might be installed to prevent long-term leakage. Wastes generated, mainly contaminated flowback water that must be treated or injected into the sub-surface, and particle and specifically GHG emissions (CH_4 is an effective GHG) must be controlled (e.g. MacKay and Stone 2013; Rostron and Arkadasky 2014). Flowback water must be stored in tanks rather than ponds at the well pad for safety reasons.

The dominant technology requirements are:

- Deep multi-stage horizontal drilling and fracturing techniques at great depth.

- Long-term monitoring of seismicity and well integrity.

Horizontal drilling is generally reserved for deep wells because it is cheaper to drill a larger number of vertical wells at shallow depths. In addition, shallow horizontal wells pose a greater environmental risk. Multi-stage horizontal drilling to free deep-seated gas begins with bending the well-shaft from the vertical to drill horizontally through the gas-shales. Subsequently, the permeability of the rock is increased by injecting a customised mix of fluids, chemicals and high-quality sand at extremely high pressure, typically between 400 and 1 000 bar, to fracture the target rock; following fracturing, permeability is retained by creating a network of open fractures through which the gas can flow. This is typically induced more than 2 - 5 km below the surface and up to 3 - 5 km laterally from the well-head, allowing the well-bore to intersect a great part of the reservoir, as well as a greater number of existing natural fractures.

Drilling and fracturing sites require the construction of well pads, work-camps, roads and pipelines. Shale gas liberation requires a relatively large degree of these activities because:

- The reach of individual wells in low-permeability rock is far less than it is in highly permeable rock.
- Production of individual horizontal wells can decline fast so more wells and hydraulic stimulations are usually needed to sustain stable gas-extraction rates.

Fracturing is usually performed by medium to large specialised service companies rather than the company operating the well, and the first well of multiple wells in one well pad is usually completed over two to four months. Smaller companies provide specialised services such as perforating, materials provision, pumping capacity, data management, supervisory control and data acquisition services.

4.1.2.5 Well Construction to Enable Hydraulic Fracturing

Section 6.1 presents a detailed description of the complex and sophisticated technology required to ensure that well construction is carried out according to best international practice. Well pads are constructed before wells can be drilled. The pads for shale gas extraction are generally two to three hectares in extent. The pads must be nearly horizontal and built with good quality fill approximately 0.5 - 1.5 m thick, depending on the nature of the subgrade. The well pad itself is typically constructed with fill excavated at or near the pad, and the resulting pit is often used to store the water to be used in fracturing. If no local fill is suitable, access to a more distant source is necessary, with trucks hauling the pad construction material. A pad for multiple directional horizontal shale gas wells may take up to several months to construct and up to 500 to 800 truckloads

of fill if none is available locally. Good plastic sheeting (or even concrete pads) on and around the pad is required to ensure no flowback fluid contamination of soils and surrounding ecosystems.

Before carrying out a multi-stage hydraulic fracturing operation, geoscience and geo-mechanics studies must be carried out to estimate the maximum growth (height and width) of induced fractures so that they will not extend significantly above the prospective shale gas horizon. Such estimates are generally based on numerical modelling and on previous experience in similar conditions. Models must be continuously refined through time from new measurements during and after the initial hydraulic fracturing operations.

Micro-seismic monitoring of the first multi-stage hydraulic fracturing is a prerequisite at all wells. In the early stages of field development, continuous monitoring yields much information about the lateral and vertical extent of the fractured zones. Empirical analysis to improve the design of multi-stage hydraulic fracturing treatments is necessary because the numerical models for fracture propagation prediction in naturally fractured rock have significant uncertainties and must be continuously re-calibrated with newly acquired information. Even with such re-calibrations, considerable uncertainty remains, but not to the extent that fractures could propagate in an uncontrolled manner.

Once the well pad is constructed, drilling can begin. Once full-scale drilling is under way, an optimisation approach using real performance data to seek the best multi-stage hydraulic fracturing design and approach for a well with a set of physical parameters (thickness, permeability, natural fracture intensity, stiffness, in situ stress fields), should be enforced so that future wells can be developed close to their maximum potential and safety.

4.1.2.6 Hydraulic Fracturing in Action

Depending on local geological conditions, the horizontal well section may be from 1 - 5 km long. Because it is difficult to maintain the required injection rate to fracture the shale surrounding the entire horizontal well-length efficiently in a single operation, the fracturing is done in stages, more-or-less evenly along its length. Small explosive devices are used to sequentially shoot holes through the casing and cement to enable the well to be hydraulically fractured in stages, usually starting farthest from the well-head (at the 'toe') and moving backwards (towards the 'heel', closest to the vertical section), using one of several different methods. During hydraulic fracturing, the formation is pressurised to extend fractures through the width of the shale horizon. The distance between fracture stages depends on local conditions, but typically ranges from 100 - 300 m, with up to 15 to 30 stages along the length of the horizontal part of the

well. During the injection phase, between four and 24 fracturing trucks simultaneously operate at top output, with other engines operating blenders and pumps, thus the noise level will be substantial.

The thickness of the shale, in particular, governs the type of fracturing and the pressure needed. The propped zone, combined with the zone of shear dilation that surrounds it, is called the stimulated reservoir volume. An analysis of micro-seismic data of 12 000 hydraulic fracture stimulations indicates that induced fracture heights above any horizontal well-bore are limited by the volume of hydraulic fracturing fluids injected; and that the reach of the fractures generated is relatively small (up to 300 - 600 m), compared to the depth of the well (often 2 - 3 km; e.g. Council of Canadian Academies, 2014).

Monitoring to enhance the effectiveness of the gas extraction process involves tracking all injection parameters (e.g. rate, pressure, compositions, temperature and density) continuously, particularly in the first wells. Micro-seismic data are used to delineate the extent (width and height) of the stimulated zone so that future multi-stage hydraulic fracturing operations in the same field must be designed efficiently to avoid out-of-zone fracturing and potential upward escape of fluids. Deformation monitoring can provide information about the shape and extent of the zone by measuring minute changes in the inclination of the ground during fracturing and flowback. After the well is producing, performance data are collected and optimisation analysis is performed to help improve treatment strategies for other wells in the region.

4.1.2.6.1 Fracturing Fluids

The fracturing fluid used is called slickwater. It contains viscosity-reducing agents to allow the fluid to travel further into the rock fractures with lower pressure losses, and viscosity-enhancing gels that help carry sand or ceramic grains (proppants) into the rock fractures. In many cases, both are used sequentially in each fracture stage to maximise both the sand penetration and the stimulated volume. Geological conditions sometimes preclude the use of slickwater, if, for example, the shales contain clays that swell when in contact with water. This requires different fracture fluid formulations that may include appreciable amounts of potassium chloride or other salts that inhibit clay swelling. It is unlikely that swelling clays are present at the depths of the shales that will be explored for gas in the Karoo, since the Whitehill Formation comprises roughly 16% illite (a non-expanding clay-like mineral), 15% muscovite and 8% chlorite.

Alternatives to water-based fracturing fluids include propane or butane-based liquefied petroleum, carbon dioxide and nitrogen gases, or foams. Gas-based hydraulic fracturing reduces recovery time and creates less formation damage but is more expensive. Propane is also flammable,

making the treatment slightly more dangerous. The industry is evolving fast and new biodegradable and saline slickwater fluids are likely to be available by the time hydraulic fracturing is likely to start in the Karoo.

The proportion of chemical additives in slickwater fracturing fluids is typically small (about 1 - 2% by volume or less) but the quantities of water required for most fracturing operations can lead to significant amounts of the chemicals being used (e.g. 1% of a 10 000 m³ hydraulic fracture stimulation, for example, would be 100 m³ of chemical additives). Most of the chemicals are non-hazardous, such as guar gum, a naturally occurring polymer, but given that only a few micrograms per litre of some additives could contaminate drinking water, sound management of these chemicals at the surface is essential to protect both human and environment health. According to ACOLA (2013), hydraulic fracturing fluid typically contains between three and twelve additive chemicals, with each additive serving a specific purpose. Table 4-1 lists some common hydraulic fracturing fluid additives (ACOLA, 2013).

Table 4-1: Typical hydraulic fracturing fluid additives (ACOLA, 2013)

Additive Type	Main Compound(s)	Purpose	Common Use of Main Compound
Diluted Acid (15%)	Hydrochloric acid or muriatic acid	Help dissolve minerals and initiate cracks in the rocks	Swimming pool chemical and cleaners
Biocide	Glutaraldehyde	Eliminates bacteria in the water that produce corrosive byproducts	Disinfectant, sterilise medical and dental equipment
Breaker	Ammonium persulfate	Allows a delayed break down of the gel polymer chains	Bleaching agent in detergent and hair cosmetics, manufacture of household plastics
Corrosion inhibitor	N, n-dimethyl formamide	Prevents the corrosion of the pipe	Used in pharmaceuticals, Acrylic fibers, plastics
Crosslinker	Borate salts	Maintains fluid viscosity as temperature increases	Laundry detergents, hand soaps and cosmetics
Friction reducer	Polyacrylamide	Minimises friction between the fluid and the pipe	Water treatment, soil conditioner
	Mineral oil		Make up remover, laxative, candy
Gel	Guar gum or hydroxyethyl	Thickens the water in order to suspend the sand	Cosmetics, toothpaste, sauces, baked goods, ice-cream
Iron control	Citric acid	Prevents precipitation of metal oxides	Food additives, flavouring in food and beverages; lemon juice ~ 7% citric acid

Additive Type	Main Compound(s)	Purpose	Common Use of Main Compound
KCl	Potassium chloride	Creates a brine carrier fluid	Low sodium table salt substitute
Oxygen scavenger	Ammonium bisulfite	Removes oxygen from the water to protect the pipe from cross-linkers	Cosmetics, food and beverage processing, water treatment
pH Adjusting agent	Sodium or potassium carbonate	Maintains the effectiveness of other components, such as crossliners	Washing soda, detergents, soap, water softener, glass and ceramics
Proppant	Silica, quartz sand	Allows the fractures to remain open so the gas can escape	Drinking water filtration, play sand, concrete, brick mortar
Scale inhibitor	Ethylene glycol	Prevents scale deposits in the pipe	Automotive antifreeze, household cleansers, adn de-icing agent
Surfactant	Isopropanol	Used to increase the viscosity of the fracure fluid	Glass cleaner, antiperspirant, and hair colour fluid

Although most of these chemicals are listed on the internet, there seems to be secrecy surrounding the exact combinations and mixtures. Oil companies claim that these chemical mixtures depend on local conditions and must be determined during exploration. In the USA, federal law was changed, and became known as the Halliburton Loophole, in order for hydraulic fracturing companies not having to disclose their chemicals, as it can be considered propriety information and a patented process. Currently a new Act, the Fracking Responsibility and Awareness of Chemicals Act (FRAC Act) is in preparation to counter the Halliburton Loophole.

Once a hydraulic fracturing stage is completed, the injected fluids are allowed to flowback until the next fracturing stage begins. Flowback of fracturing fluids occurs slowly and at a diminishing rate as the well starts to produce gas. Natural gas that accompanies the flowback fluid must be recovered and not flared. The fracturing process is repeated until the well is completed. Flowback fluid is a combination of the returning hydraulic fracturing fluid (slickwater) and water from the shale formation which may have salinity between 10 gm/l and 100 gm/l total dissolved solids (TDS). In addition, the flowback may also contain naturally occurring radioactive materials (NORMs), metals and organic compounds liberated from the shale.

Recycling of flowback water in subsequent fracture stages or transport to another well pad for reuse reduces the amount of freshwater used for hydraulic fracturing, but some shale gas deposits will not return any formation water to the surface. As a general rule however, 30 - 40% of

slickwater will be recovered from hydraulic fracturing, although it can be much greater or much less (10 - 110%) depending on the formation. The flowback water removed during each stage is initially stored at the well pad. It is either treated or reused in the next stage. Such treatment would probably produce brine that would have to be disposed of, possibly in part by evaporation to minimise the volume to be removed, for which there would also be environmental concerns. The risk associated with an accidental spill to the groundwater should be low if proper site management and emergency procedure protocols are developed, prescribed and applied.

Perhaps 5 - 10% of the flowback water will end up being deep-well injected because of its salinity or, treated for release into surface water or perhaps evaporated. Technical and economic limitations influence the degree of feasible recycling in different areas. Because of its high salinity and the presence of divalent cations, flowback water often needs treatment or more additives before it can be reused and is generally less effective for fracturing than fresh water.

Among the advances for minimising the use of fresh water for hydraulic fracturing is the use of saline groundwater. For saline water to be effective it may be necessary to increase the quantity of additives, such as viscosity-modifying agents, adding to the costs. Saline water in sufficient quantities is readily available from productive aquifers in the Karoo (e.g. Weckman *et al.*, 2012). The Oudtshoorn Basin (also known as the Klein Karoo), for example, may be geologically suited to massive deep wastewater disposal because thick permeable saline aquifers are available at relatively shallow depths (>0.5 - 1.5 km). Whilst the use of saline-water as an alternative to fresh water is still in the early stages of development, neither propane nor CH₄ fracturing requires water. Propane can be gelled into liquid form to transport sand into the fractures, but CH₄ cannot. Neither of these approaches nor liquid carbon dioxide and nitrogen fracturing cause formation damage.

4.1.2.6.2 Sand (proppant)

Once the fractures in the shale are created, sand is added to prop open the fractures to allow free gas to flow from the now highly permeable gas-shale. The great majority of the propping agents used are high purity, well-rounded quartz sand ("frac sand"), carefully sieved and provided in bulk in a narrow range of grain size. Large sand grains are difficult to transport long distances into the fracture network during injection, but small sand grains are less effective in maintaining a large conductive fracture aperture.

Most are between 0.4 - 0.8 mm in diameter. Artificial ceramic spherules are sometimes preferred, but these are considerably more expensive.

4.1.3 Summary

- Based on recent geological and geochemical evaluations, the Karoo shale gas is a resource with probably between at least 19 and 23 tcf of available free gas across a selected area ranging between 60 000 - 100 000 km². These numbers may decrease if sensitive UNESCO World Heritage sites are deemed 'out of bounds' for gas exploitation (Figure 4-2). However, the 3-D geology of the Karoo is poorly known, and remote geophysical sensing and deep cored drill-holes must be implemented during a first exploration phase to determine subsurface distribution of gas-shales and location of 'sweet spots' to establish with greater accuracy the total potential recoverable gas-shale in place.
- Exploration for shale gas in the Karoo should be carried out in two separate phases. During both phases, quantitative knowledge about groundwater resources of the Karoo will vastly improve. Limited multi-directional hydraulic fracturing at selected pads will be needed during a second exploration phase to evaluate the retrieval success of the shale gas and how efficiently the gas can be harvested to determine its economic return, and its status as gas reserve. It is recommended that a second, controlled, 3-D EIA should be undertaken, including deep seismic monitoring and modelling, before the second exploration phase commences.
- Regions where gas-shales occur at less than 1 - 1.5 km depth below surface, and even if rich, should be avoided at least until the geology is better understood, and the hydraulic fracturing and casing technologies improve (Jackson, *et al.*, 2015; DiGiulio and Jackson, 2016). This eliminates a substantial part of the Karoo Basin for initial exploitation targets, including regions surrounding the SALT and the SKA.
- A major recommendation to address the challenges highlighted in this section is for South Africa to design and build an experimental drilling and controlled hydraulic fracturing research laboratory, linked to a technical shale gas training college possibly located in the Eastern Cape, where drilling experiments and hydraulic fracturing tests can be carried out under controlled conditions and with mandates that will attract competent researchers and mentors to help develop local monitoring skills and regulatory requirements to assure a competent and transparent shale gas industry.
- South Africa has a history of inadequate controls when it comes to externality costs related to mining and abandoned mines. 'Cradle to grave' plans are seldom in place. This must be avoided at all costs in the case of shale gas exploitation in the Karoo, starting right from the first exploration phase.

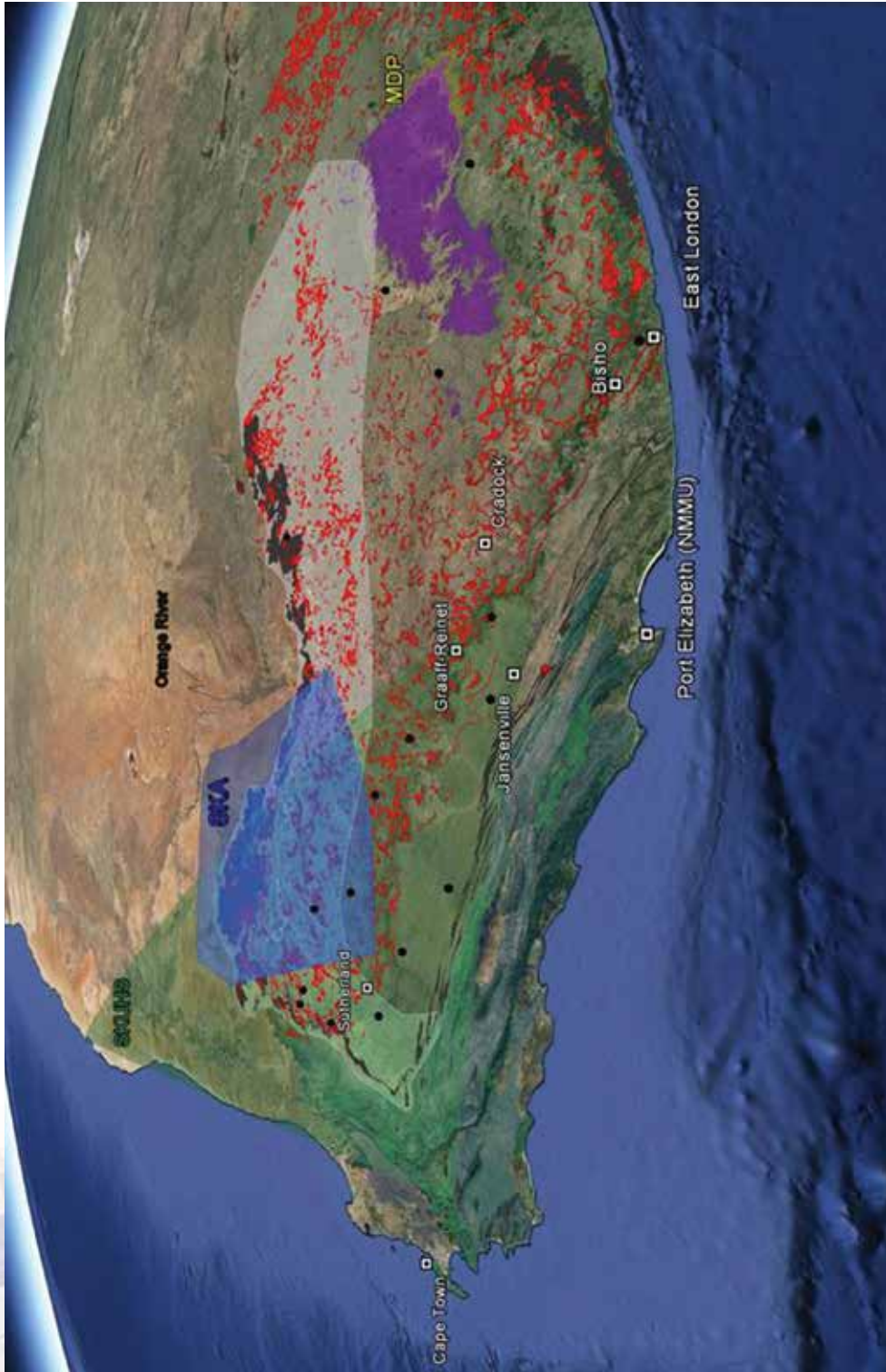


Figure 4-2: Summary map of potential shale gas locations in the Southern Karoo, relative to important potential constraints limiting its exploration/exploitation (AEON map using Google and digital geologic and ecological information)

Note that the potential exploration/exploitation area for shale gas is reduced further than that shown in Figure 4-1 (as based on geological information only), by including the Succulent Karoo UNESCO World Heritage (SKUHS) site (green triangle), leaving only an area between Cradock-East London-Jansenville for initial shale gas exploration without substantial environmental/biodiversity risks. The transparent white overlay is the area where the shale gas horizon occurs at depths of less than 1 500 m, and should be excluded from any hydraulic fracturing activities. Note that this would therefore exclude most (95%) of the SKA area (blue overlay) and SALT (at Sutherland) from shale gas exploitation in the foreseeable future. In terms of geology the red lines indicate dolerite sills, and associated Drakensberg Volcanics in purple. Toward the south, blue indicates the Cape Supergroup of the Cape Mountains; the black-shaded area indicates surface exposures of the main gas-shale (Whitehill Formation); note how this unit is intensely folded (and reduced in gas) along the northern edge of the Cape Mountains. Also shown along the Cape Mountains are green overlays of important UNESCO plant biodiversity sites that should be avoided during planning of truck traffic into the potential Karoo shale gas exploration sites. Large prominent black dots indicate deep SOEKOR drill sites; red dots indicate African Earth Observation Network – Nelson Mandela Metropolitan University (AEON-NMMU) drill sites (e.g. Geel *et al.*, 2015). (MDP: Maloti-Drakensberg Park).

4.2 Issues of Water, Sand, Air and GHG Emissions

4.2.1 Introduction

The potential impacts of hydraulic fracturing on water security as well as on water quality are highly contentious issues. Many of the concerns about water security cannot be substantiated or rebutted by supporting data and information about groundwater systems at depths in excess of 1 000 m and their association and interaction with shallow aquifer systems. This is because there is a lack of such information for the South African context.

The volumes of water required for the hydraulic fracturing process, as well as the possible impacts on water quality, necessitate that a holistic approach be followed in addressing these concerns, as both surface water and groundwater could be impacted upon. All potential impacts will have to be evaluated from a quantitative as well as a qualitative perspective.

Uncertainty and possible sources of concern regarding the potential impacts of hydraulic fracturing on groundwater, surface water and air include:

- The uncertainty about the locations of possible hydraulic fracturing sites, as well as the scale of operations if exploration, provides positive results.

- Sources of water for the hydraulic fracturing processes.
- Flowback that is likely to occur after pressurisation of the well system by the hydraulic fracturing process. Some of the hydraulic fracturing fluid mixture flows back (between 10 and 110 %) (US EIA, 1993; Argonne, 2009; Vidic *et al.*, 2013) to the surface, possibly carrying additional environmentally detrimental constituents, e.g. naturally occurring radioactive materials (NORMs) or other problematic trace elements contained in the shale.
- The role of possible preferential flow pathways associated with intrusive structures, e.g. dolerite dykes and sills, fault zones and kimberlites that might act as preferential pathways for the migration of pollutants or for naturally occurring groundwater of very poor quality towards the surface aquifers that are utilised for groundwater supplies.
- Unknowns regarding the behaviour of deep aquifer system(s) in the Karoo formations. Current research is only relevant to a depth of 300 m, however deep artesian groundwater was recorded during the exploratory deep drilling for oil by SOEKOR in the southern Karoo, below the escarpment. Water strikes were located in fractured rocks of the Dwyka and Peninsula Groups at around 3 000 m depth. This has led to differing opinions between experts: some argue that local artesian pressure (head in the Cape Fold Belt or in the escarpment) is responsible, while others claim that it is indicative of a general upward gradient towards the surface in the Karoo Basin. Detailed information on water quality in these deep exploratory boreholes was not recorded and there is little knowledge of this potential source of pollution.
- Wastewater treatment and disposal. After treatment of the fracturing fluid mixture, a highly saline brine remains as a by-product unless the mixture is treated to zero-liquid discharge standards, a cost and energy-intensive treatment scheme.
- Chemical ingredients and additives to the hydraulic fracturing fluid.
- Hydraulically fractured wells that could artificially connect several aquifers with different water qualities.
- Increased induced seismic activity stemming from the disposal of produced water via deep-well injection.
- Specifications for an early warning system for long-term monitoring of water quality of production, as well as defunct wells.
- Possible future effects of abandoned production wells.

- Sources of sand to be used as proppants in the hydraulic fracturing fluid if these are not specially manufactured.
- Casings and cemented annuli of completed wells that are compromised during the production phase and could allow the migration of volatiles and contaminated groundwater into shallow fresh water aquifers along a pressure gradient during the production phase; and the long-term integrity and monitoring thereof.
- Spills of flowback water and produced water at the ground surface or during transportation for disposal.

4.2.2 Water and Chemical Requirements for Hydraulic Fracturing

4.2.2.1 Hydraulic Fracturing Well Layouts

The equipment at hydraulic fracturing wells for dealing with water and flowback and produced water will probably be similar to that used for hydraulic fracturing in other countries (M. Mauter and G. Thonhauser, pers. comm. February 2015). The equipment at a typical Canadian shale gas site is described in the report of the Council of Canadian Academies (2014) as follows:

- 1 Data/satellite van: to monitor and control treatment operations. Satellite transmission of data to enable real-time monitoring from remote locations.
- 2 Sand (proppant) storage silos, sand conveyors, two-day silos over blenders: To store sand and to feed it to the blender mixing tub (underneath).
- 3 Multiple well-heads (shrouded for safety reasons during the stimulation operation).
- 4 Pumping units: high-pressure pumps to pump the fluid.
- 5 Chemical vans and tanks: storage, transportation, and metering units used to feed additives into fracturing fluid stream as it is pumped down the well.
- 6 Test equipment: to receive and measure flowback water in a controlled manner. The equipment is also used to separate fluids from gas, which is sent to be flared.
- 7 Water surge tanks: tanks to prevent pressure surges and provide smooth water supply to the operation. In this operation fresh water is pumped from storage ponds. No flowback water is stored on the surface, it is pumped directly to disposal wells after separation from the produced gas. In some jurisdictions, lined ponds may also be used to store flowback water that is treated and reused.

4.2.2.2 Water Requirements

It is essential that hydraulic fracturing of wells should take place at each concession during the exploratory phase in order to provide an indication of the water requirements for drilling and hydraulic fracturing so that the sourcing of water for the production phase can be planned (M. Mauter and G. Thonhauser, pers. comm. February 2015).

4.2.2.2.1 Exploratory Phase

The exploratory phase is usually utilised to establish a baseline for local operations at the well pad and also the likely baseline requirements for water use and flowback (M. Mauter and G. Thonhauser, pers. comm. February 2015). The exploratory phase should include the hydraulic fracturing of at least three wells.

4.2.2.2.2 Development Phase

The development phase at each well pad comprises a detailed planning phase, followed by the gas production phase which includes the drilling of a number of wells, typically ten to 20 horizontal wells, and thereafter the hydraulic fracturing of the wells as a continuous process (M. Mauter and G. Thonhauser, pers. comm. February 2015). Given that the technology is changing rapidly it is recognised that such an approach may be modified in the future.

The processes at each well pad which determine the water supply requirements and the flowback from each well that is drilled during the development phase are usually as follows:

- 1 Detailed planning of the development phase for the drilling and hydraulic fracturing of ten to 20 or more wells in continuous succession at a well pad include the following:
 - The sourcing of water.
 - The storage of water on site.
 - The storage of flowback and produced water.
 - The treatment and reuse of flowback and produced water.
 - The disposal of excess flowback and produced water.
 - Managing volatile organic compounds (VOC) emissions during produced water storage, reuse, treatment, and disposal.^{16, 17}

¹⁶ <http://pubs.acs.org/doi/full/10.1021/es405770h>.

¹⁷ <http://dept.ceer.utexas.edu/methane/study/>.

- 2 The water requirements for drilling and hydraulic fracturing of a typical well are described below:
 - Water requirements for the drilling phase are typically as follows:
 - A 12 $\frac{1}{8}$ inch intermediate section drilled to a depth of about 2 200 m would require about 330 m³ of water-based mud (WBM) for drilling mainly comprising water.
 - An 8 $\frac{3}{4}$ inch production section drilled vertically and then horizontally with a total length of about 4 500 m, would also require some 320 m³ of WBM for drilling.
 - Water requirements for the hydraulic fracturing and flowback phases are as follows (M. Mauter and G. Thonhauser, pers. comm. February 2015):
 - Staged hydraulic fracturing of the horizontal sections of each well takes place by pumping hydraulic fracturing fluid at very high pressure into the well, typically at a rate of about 13 m³/min (220 l/s). The typical volume of water required for the hydraulic fracturing of a well (for each horizontal well on a pad) is expected to be about 6 800 m³ but could be between 3 800 m³ and 26 300 m³. The typical flowback volumes from hydraulic fracturing of the Whitehill Formation will only be known after the test hydraulic fracturing has been undertaken during the exploratory phase.
 - After the hydraulic fracturing of a well is completed, flowback occurs. The volume of flowback depends on the characteristics of the shale formation and could be between 10% and 110% (based on say 100% of hydraulic fracturing fluid plus 10% from the formation) of the volume of the hydraulic fracturing fluid pumped into the well. As the flowback contains gas including VOCs, it is stored in sealed containers from which the gas may be removed and used on site or it may be vented and flared.
 - 80% of the flowback usually occurs within the first 21 to 35 days after hydraulic fracturing.
 - Flowback and produced water may be disposed of off-site, treated for reuse off-site, or treated for reuse on-site. On-site treatment is most commonly basic treatment in which dissolved hydrocarbons, suspended solids, and bacteria are removed. Desalination is more commonly performed off-site.
 - Opportunities for reuse of flowback and produced water are

likely to depend on the salinity and volume of the water, as well as on the composition of chemicals deployed in the fracturing operation. Many companies have successfully reused very high salinity waters (>100,000 ppm TDS) without requiring desalination.

- The maximum estimated water use per well of 26 300 m³ is similar to that for shale gas wells in the USA as is evident in ACOLA (2013). It should be noted that water use per well is a function of the length of the lateral well and as these increase more water is used.
- Hydraulic fracturing of each well typically takes between 28 and 42 days. For a pad with ten wells, this can extend for six months to two years. Again it needs to be noted that given the rapid development in the technology of hydraulic fracturing these time periods could reduce significantly.

Table 4-2 shows a number of possible water use scenarios which indicate the following:

- As mentioned above, the water required to drill and hydraulically fracture the first of between ten and 20 horizontal wells at a well pad is expected to be about 6 800 m³ but could be between 3 800 m³ and 26 300 m³.
- The water requirements for hydraulic fracturing of additional wells at a well pad are expected to require a continuous water supply of about 0.09 m³/min (1.5 l/s) for the expected average requirement of 6 800 m³/well, assuming 50% flowback and assuming that 95% of the flowback water is reused.
- Table 4-2 also indicates that the water requirements for hydraulic fracturing could be zero but could be as high as about 0.6 m³/min (10 l/s).

Table 4-2: Estimates of water use for hydraulic fracturing

		Minimum Water Use			Typical Water Use			Maximum Water Use		
Water use/Well	m ³	3 800	3 800	3 800	6 800	6 800	6 800	26 330	26 330	26 330
Pumping rate for hydraulic fracturing	m ³ /min	13	13	13	13	13	13	13	13	13
Time to inject water	days	0.20	0.20	0.20	0.36	0.36	0.36	1.41	1.41	1.41
Flowback	%	10%	50%	110%	10%	50%	110%	10%	50%	110%
Flowback storage	m ³	380	1 900	4180	680	3 400	7 480	2 633	13 165	28 963
Period	days	28	28	42	28	28	42	28	28	42
95% flowback for next well	m ³	361	1 805	3 971	646	3 230	7 106	2 501	12 507	27 515
Volume of fresh water for each subsequent well	m ³	3 439	1 995	-171	6 154	3 570	-306	23 829	13 823	-1 185
Average flow	l/s	1.42	0.82	-0.05	2.54	1.48	-0.08	9.85	5.71	-0.33

If the water supply that is required is as low as 0.09 m³/min (1.5 l/s) then it may be possible to source the water from one or two typical shallow boreholes in the Karoo and to deliver this via a pipeline or perhaps via about three to four 40-ton tanker truck loads per day,

If the water requirement is 0.6 m³/min (10 l/s) then it might be possible to source water from a well field comprising a number of typical Karoo boreholes but it seems unlikely that this would be feasible. If water is sourced remotely then this would probably have to be delivered via about 22 40-ton truck loads each day or perhaps via a pipeline.

In view of the possible impacts of utilising shallow boreholes on the yields of existing boreholes, it has been suggested that if feasible it may be preferable to source water for hydraulic fracturing from deep saline aquifers (Mauter *et al.*, 2014). Companies should be required to survey the possible availability of saline aquifers prior to sourcing from freshwater aquifers.

It is evident that the exploration phase of shale gas development should include hydraulic fracturing in order to establish the likely water requirements and also the flowback and produced water volumes from hydraulic fracturing. It is also recommended that the exploration phase should include deep drilling for water to establish whether there are deep saline aquifers from which withdrawals could be made that would not affect existing shallow groundwater supplies. However, the sustainability of such deep and probably old water is unknown.

4.2.3 Water Availability

South Africa is currently considered to be water stressed and it is predicted to become a water scarce country by 2025 due to the increase in population and the associated increase in water usage. Currently South Africa has less than 1 700 m³/person/annum and this situation will worsen by 2025 when the volume of water per person per annum (p.a.) is expected to be less than 1 000 m³.¹⁸

The Karoo is situated inland of the coastal mountain ranges in the relatively dry interior of South Africa. The mean annual rainfall in the Karoo varies from about 100 mm to 300 mm, except in the east where the rainfall is slightly higher. The mean annual evaporation varies from 2 000 mm p.a. to 2 300 mm p.a. (Smart, 1998). Runoff usually arises from localised summer thunderstorms which cause high flows in small catchments. Major weather systems such as cut-off low pressure systems occasionally cause major floods. Most Karoo towns rely on groundwater for their water supplies on account of the sporadic rainfall, low runoff and high evaporation.

A comparison of the typical supplies to Karoo towns shown in Table 4-3 with

¹⁸ <http://www.wri.org/blog/2013/12/world%E2%80%99s-36-most-water-stressed-countries>.

the potential water requirements for the production phase of hydraulic fracturing shown in Table 4-2, suggests that it may be possible to develop shallow groundwater well fields to supply the typical water requirements for hydraulic fracturing of about 0.09 m³/minute (1.5 l/s) provided that this would not prejudice existing groundwater supplies. Table 4-3 also indicates that it is very unlikely that small surface water schemes could supply water for hydraulic fracturing at an acceptable reliability.

However, large reliable surface water sources of supply such as the Orange-Fish water transfer scheme, or perhaps Beervlei Dam (if temporarily used for storage of the relatively saline runoff) could perhaps be considered as possible sources of supply via pipelines or possibly by tanker truck. Should groundwater or surface water be considered to be feasible sources of supply then it would be necessary to purchase or arrange the transfer of the water use licence.

Table 4-3: Sources of water supply for some Karoo towns (DWA, 2011a and b)

Town (Year)	Population	Sources of Supply (m ³ /minute)/(l/s)/(million m ³ /annum)		
		Surface Water	Groundwater	Total
Merweville (2006)	1 240		0.23/3.8/0.12	0.23/3.8/0.12
Leeu Gamka (2007)	2 234		1.90/31.7/1.00	1.90/31.7/1.00
Beaufort West (2007)	33 324	1.98/33.0/1.04*	2.96/49.5/1.56	4.94/82.5/2.60
Nelspoort (2007)	1 485	0.19/3.2/0.10	0.08/1.3/0.04	0.27/4.4/0.14
Murraysburg (2005)	4 416		0.55/9.2/0.29	0.55/9.2/0.29

**Beaufort West's surface water supplies failed during the recent drought necessitating the construction of a reverse osmosis scheme which treats wastewater by reverse osmosis to supply about 0.84 million m³/annum.*

As the sourcing of water from shallow groundwater or from surface water is likely to impact on existing water usage, it would seem to be preferable to source the water for hydraulic fracturing from deep saline aquifers if these can provide sufficient supply and are not too remotely located. It has even been suggested that seawater should be imported from the coast, however it would seem to be preferable to source the water from a location closer to the hydraulic fracturing well pad sites, if this is feasible. The reuse of flowback water for hydraulic fracturing can considerably reduce the supply requirements from other sources and also the volume of flowback water to be disposed of, possibly by evaporation or perhaps by disposal in deep wells.

4.2.4 Hydrogeology

A variety of groundwater systems occur within the Karoo Basin due to its heterogeneity. An aquifer is defined as a saturated permeable geological unit that is permeable enough to yield economic quantities of water to

wells (Krusema and De Ridder, 1994). The basic aquifer types include unconfined or water table systems, confined systems and leaky, semi-confined aquifer systems.

Sometimes aquifers are described according to their porosity, with primary aquifers defined where porosity is an inherent characteristic developed during the formation of the rock and secondary aquifers where porosity is developed due to subsequent processes such as fracturing, jointing, and solution activities that occur after formation,

Considering the above, two types of aquifers are of interest in the Karoo Basin. Aquifers associated with unconsolidated sediments in the form of alluvial deposits in the floodplains of major river systems can be considered as primary porosity aquifers. These primary aquifers are very dependent on recharge occurring during high flows and floods during the summer rainfall season. Fractured aquifers (secondary porosity aquifers) are more widespread and extensive in the Karoo. Water is stored in and flows through fractures and fault systems. Depending on the areal extent and inter-connectedness of these fracture systems, very low to high-yielding boreholes can be drilled within the Karoo fractured aquifers.

Currently, most of the groundwater abstraction in the Karoo is from the shallow fractured and weathered aquifers (20 - 100 m) systems. Water Research Commission (WRC) projects provided information regarding contact zones between dolerite formations and the host sedimentary formations (Chevallier *et al.*, 2004). First of all, definite compartmentalisation of aquifers occurs, as well as multi-fractured aquifers to a depth of at least 250 m. Pressure tests on the boreholes indicate that open fractures can cover areas of hundreds of metres, at least to a depth of 250 m. No link could be established between the semi-deep aquifers and the shallow aquifers due to a confining environment. However, from a hydraulic fracturing perspective, it must be noted that vertical and horizontal drilling can create artificial connections between these aquifers with the concomitant possibility of leaking fluids or gas. Well construction through the shallow fresh water zone should therefore be considered as one of the critical phases during the construction phase.

Shallow aquifers are very dependent on recharge from rainfall. Annual rainfall in the Karoo is low and intermittent, with evaporation significantly exceeding precipitation as mentioned above. Recharge to these shallow aquifers is usually associated with preferential flow through cracks and fractures, while some recharge occurs through diffusive flow through the unsaturated zone. Climatic conditions have a substantial influence on the recharge that replenishes the shallow aquifers. Human and agricultural activities place additional strain on available groundwater resources.

Older shallow boreholes drilled by farmers within the shallow aquifer systems are generally associated with unconfined and recharged conditions, while boreholes drilled by DWS are more likely to encounter deeper confined or semi-confined conditions. Flow within both types of aquifer systems will occur mostly along preferential pathways (fractures), the exceptions being boreholes associated with alluvial deposits in the floodplains of more prominent rivers, where porous flow occurs.

The quality of groundwater in the shallow aquifers throughout the Karoo Basin improves from west to east as well as from south to north in the eastern parts (Rosewarne *et al.*, 2013). Geology, agriculture and other human activities influence water quality on a local scale (Foster *et al.*, 2002). There is very limited information available about South Africa's groundwater systems that are deeper than 300 m. The Qoqodala project near Queenstown (Chevallier *et al.*, 2004) encountered several groundwater strikes at boreholes drilled to a depth of 250 m. These exploration boreholes which were drilled between 1979 and 2004 by the DWS (then the Department of Water Affairs and Forestry) to a depth of 300 m, the technical limit of percussion rotary drill rigs at that time, yielded similar results. Below these depths the knowledge about these groundwater systems remains uncharted territory.

As mentioned above, the mechanisms of groundwater flow within the deep aquifers are not fully understood. SOEKOR's drilling activities into confined conditions at depth indicated different pressure release responses at different locations. Much more information will be required concerning geological settings and pressure gradients in order to determine the possible implications of hydraulic fracturing.

4.2.5 Water Use Licence

As part of the license application procedure, any prospective exploration company will need to submit an integrated water use license application (IWULA) to the DWS. A water use license will only be issued by the DWS if a reserve determination for the specific catchment has been carried out. The reserve defines the quantity and quality of water from a particular source that is required to supply the basic needs of people and to protect aquatic ecosystems in order to ensure ecologically sustainable development and use of water resources. This is a unique water resource management requirement of South African legislation. Companies applying for an exploration license will therefore be required to identify their sources of water supply, and to develop a management plan on how to utilise these sources and to mitigate any potential impacts. Long-term monitoring should be a condition of the license, as well as long-term liability obligations.

4.2.6 Hydraulic Fracturing

4.2.6.1 Exploratory and Production Phases of Hydraulic Fracturing

It is likely that the implementation of hydraulic fracturing in the Karoo would follow a two-phased process. The first phase would comprise an exploratory phase to determine the potential extent and feasibility of developing the shale gas resource, as well as the water requirements for hydraulic fracturing and the flowback and produced water volumes as indicated in Section 4.3.2. The first phase should also provide opportunities for obtaining more information about the deep groundwater systems of the Karoo, as well as opportunities for long-term monitoring of the behaviour of the deep Karoo aquifers.

If the first phase indicates that the development of the resource is likely to be economically viable then the second phase development of production wells would probably proceed. Therefore, it is particularly important that opportunities for the long-term monitoring of deep aquifers should be incorporated into the first phase.

4.2.6.2 Sources of Water

The sources of water to be used for hydraulic fracturing in the Karoo have not been identified and would be subject to the issue of a water use licence by DWS as indicated above. Current operational procedures in the USA indicate that flowback water is frequently recovered from each hydraulic fracturing event and is stored in special containers either to be used for the next hydraulic fracturing event or to be transported to the next location for reuse. This would reduce the water requirements but would require authorisation (Mauter *et al.*, 2014).

Applications for a water use licence for the exploratory phase of hydraulic fracturing and subsequently for the production phase would be required to indicate the volumes of water to be used, the source/s of water, the rates of abstraction, how any contaminated water would be stored on site to prevent pollution and how the contaminated water would be safely disposed of. The licence would specify these requirements, the reserve requirements and the monitoring to be provided.

4.2.6.3 Flowback and Produced Water

Flowback water that cannot be reused is of concern and handling procedures should be scrutinised in order to ensure that there is zero or minimal impact to the environment. In the USA, much of the flowback and produced water is disposed of in deep wells, accessing confined geological formations. South Africa may not have that option and flowback water may have to be treated.

Due to uncertainties associated with the deep aquifer systems in the Karoo, the volumes of produced water during the production phase of a hydraulic fractured well are still unknown. The quality of produced water is expected to be very poor and to have a high salinity (Section 4.1.2.6.1).

4.2.6.4 Preferential Flow Paths

Considering the possibility of local or regional upward gradient, there is concern that preferential flow paths might exist from depth. A preferential pathway is any structure of land alteration or condition resulting from a naturally occurring process or human activity which would increase the probability of a contaminant reaching a drinking water source. In the Karoo Basin, preferential pathways can be associated with dolerite dykes and sills, fault zones, kimberlite pipes and borehole construction. These naturally occurring geological features that could give rise to preferential flow paths should be identified and avoided.

4.2.6.5 Natural Occurring Radioactive Materials

Within the Karoo Basin's sedimentary formations, numerous sandstone lenses that contain NORMs are present. These sandstone occurrences should be recorded and special storage, handling, transport and disposal procedures should be developed specifically for any backflow or produced water that contains NORMs.

4.2.7 Summary

It is clear that it is very difficult to predict the possible impacts of hydraulic fracturing on South Africa's water resources due to the lack of information regarding our intermediate and deep groundwater systems. As emphasised elsewhere, a comprehensive baseline study should be initiated as soon as possible on a local, as well as regional scale.

The following proposals can be regarded as critical and should be re-evaluated as more information becomes available or additional concerns are raised.

- The technical requirements that were proposed by the Minister of Mineral Resources (RSA, 2013) should continuously reflect the rapidly evolving best international practice for a South African specific context.
- Baseline study projects should be funded in the immediate future to establish prevailing conditions which should be documented for future comparisons. These should include atmospheric, soil, surface water and groundwater (isotopes, macro, micro and metal species) environments and should be filed at the DWS and the DMR, respectively. Results must be verified by an independent body with known competency.

Data should be made available as an open database for effective monitoring of the exploration companies, as this is one of the greatest drawbacks in the international arena.

- A technical information sheet should be developed, indicating parameters that should be monitored and measured during any drilling activities, exploration, as well as production, in order to gain more knowledge regarding deep groundwater systems.
- Exploration licences should require that operators assess the extent and production rates of deep saline groundwater systems that contain non-potable water and will therefore not compete with existing uses of fresh water in the Karoo.
- Legal licensing conditions should be very strict for drilling contractors who should be made aware that they will be held liable for any deviation from these conditions as well as any environmental impacts from their drilling processes.
- Monitoring conditions should also form an integral part of the water use license issued by the DWS. This should include a requirement for long-term monitoring and provision for measures to be implemented should deterioration of the well casing and sealing cause back flow and pollution
- As part of the technical requirements, rehabilitation to natural status should be completed before any drilling contractor is allowed to leave site. Only a fenced off area, associated with production activities, should be allowed to remain.
- Best-practice guidelines should be developed and implemented. These should be based on current international drilling methods that are available for the development of gas fields and should include as a minimum but should not be limited to:
 - Drill pad preparation and drilling techniques.
 - On-site handling of chemicals, sand (proppant) and water that will be used during the hydraulic fracturing process.
 - Minimisation of air emissions through containment of wastewater, use of environmentally compliant completion practices, use of natural gas generators and natural gas vehicles, and minimiation of dust.
 - Sourcing of water from non-potable or rapidly renewable sources.
 - Waste pits and/or lagoons for containment of water and wastewater and/or the development of closed-loop drilling, elimination of in-ground impoundments for drill cuttings and fluids, impervious well pad covers, etc.

- Protection zones around existing communities, water users, existing boreholes and natural streams and rivers.
 - Allowing relevant government and regulator representatives access to operations for inspections and observation. Independent monitors from academic or research institutions should be included in these groups.
 - Handling of accidental spills on site and the immediate mitigation thereof.
 - Incident reporting when any actions could compromise the health, safety or security of individuals, communities, crops, animals or environment.
 - Long-term handling of produced water from production wells.
 - Closure and abandonment practices.
- Long-term monitoring and remedial responsibilities after production wells are decommissioned.

4.3 Potential Impact on Astronomy

4.3.1 Preamble

This section assesses the risk of detrimental impact by hydraulic fracturing and supporting activities on the SKA radio telescope, primarily located in the Karoo region of South Africa. It builds on two previous reports (Tiplady, 2011; 2012) compiled as input into the 2011 Report of the Working Group of the Task Team on Shale Gas and Hydraulic Fracturing (DMR, 2012).

4.3.2 Introduction

The SKA is a highly sensitive radio receiver, typically 15 orders of magnitude more sensitive than a standard cellular phone. When undertaking scientific observations, it will detect and measure extremely weak radio signals that are emitted, through natural phenomenon, from cosmic sources (e.g. stars, galaxies or hot/cold gas). Consequently, the single largest threat to the successful reception and analysis of these cosmic radio signals, and hence the scientific performance of the SKA, is the unintended reception of radio signals of human origin (referred to as radio frequency interference, or RFI). These can be anything from television broadcast transmissions and local Wifi networks to Bluetooth devices and even the spurious emissions of spark plugs on petrol vehicles. To mitigate this risk, the SKA is to be constructed in the sparsely populated region of the Karoo, where there is typically low demand for such telecommunication services and a low presence of electrical and industrial equipment. The Karoo has already been identified by an international panel as being one of the best locations in the world to host radio astronomy facilities by selecting it as one of two locations to host the SKA radio telescope.

The extreme sensitivity of the SKA means that even the weakest anthropogenic radio signals are detectable at some level, and in some part of the radio frequency spectrum across which the SKA will operate. To minimise the potential impact of this risk, careful management and coordination with stakeholders, acting in concert with regulatory and legislative requirements (such as the Astronomy Geographic Advantage (AGA) Act (Act 21 of 2007)), is needed. The establishment of an Astronomy Advantage Area (AAA) (sometimes referred to as a Radio Quiet Zone), protected through the mechanisms of the AGA Act, is in line with accepted practice within the International Telecommunications Union (ITU, 2012).

4.3.3 Review of Risks

There are two characteristic types of RFI associated with hydraulic fracturing and supporting activities that pose a detrimental risk to the scientific performance of the SKA:

- 1 Broadband electromagnetic interference (EMI) – resulting from the use of electrical equipment such as vehicles, arc welders, power generators and information and communications technology equipment. The nature of EMI is such that it is typically weak, but covers a large part of the radio frequency spectrum that will be used by the SKA. As a result, if EMI is detectable by the SKA, it will have an unacceptably high detrimental impact on its scientific performance. However, the source of EMI would usually have to be relatively close to an SKA station to be detectable (<30 km depending on the type of source and the intervening topography).
- 2 Narrowband RFI – resulting from the use of wireless telecommunication services, including but not limited to inter-device communication such as Bluetooth and Wifi. The nature of this type of RFI is such that it is usually significantly stronger than EMI, but covers a small fraction of the radio frequency spectrum being used by the SKA. Although this can have a lower detrimental impact (than EMI) on scientific performance of the SKA, if there are too many sources of RFI, or the RFI is so strong that it causes artefacts in the SKA receiver equipment (or even damage), the resultant detrimental impact would be unacceptably high.

Both EMI and RFI are expected to originate from a typical hydraulic fracturing site during all phases, from site establishment and construction, to operations and finally decommissioning. This may not be limited to the specific site, but can also arise from increased vehicular volumes along transport routes that may previously have had very low traffic volume densities (and therefore were an acceptable risk to the SKA).

Figure 4-3 shows the SKA Phase 1 and Phase 2 configurations, superimposed over known identified shale gas exploration areas in the Karoo region.

Whilst the layout of the Phase 1 configuration has been optimised and is close to finalisation, the layout of the Phase 2 configuration remains subject to further optimisation by the international SKA Office. The large polygon identifies the Karoo Central AAA, declared by the Minister of Science and Technology in terms of the AGA Act. Regulations promulgated in terms of the Act are aimed at protecting the SKA from detrimental sources of RFI and EMI located within this declared area through a process of assessment and authorisation with restrictions and/or conditions. The central region of the SKA configurations has the highest density of receivers, and is therefore most sensitive to sources of EMI and RFI. Optimisation of the SKA Phase 1 configuration has taken into account the road network and associated traffic volumes in the Karoo region. Whilst low traffic volumes (below approximately six vehicles per day) constitutes an acceptable risk of interference for SKA stations located near (<10 km) the respective road, greater traffic volumes would start to have a detrimental impact on the overall scientific performance of the SKA.

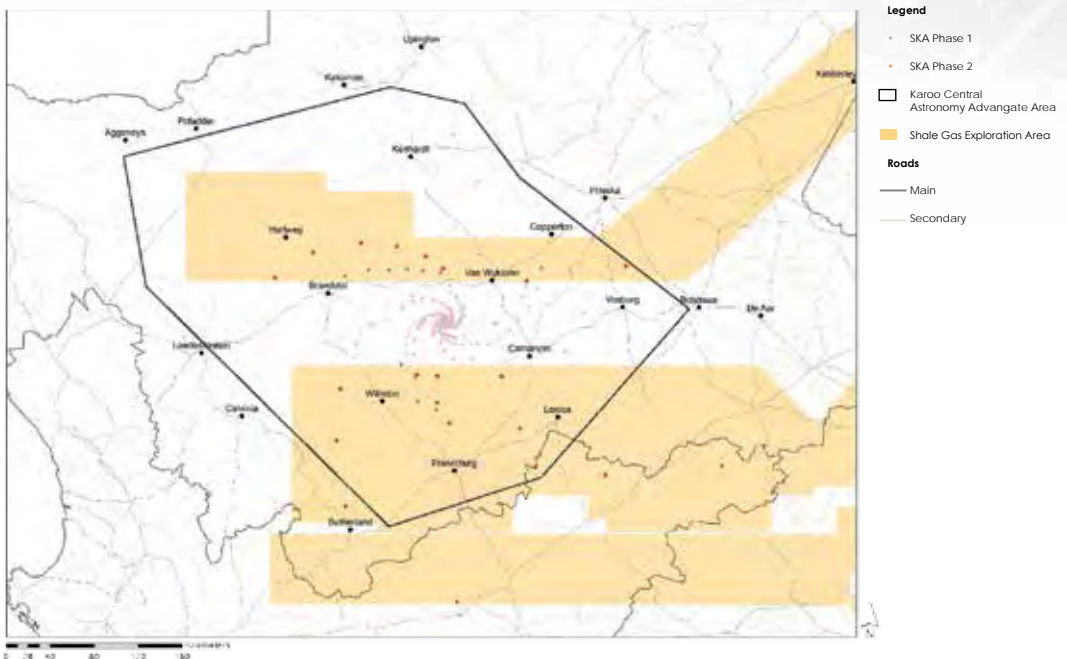


Figure 4-3: Map indicating the SKA Phase 1 and Phase 2 configuration, superimposed over the identified shale gas exploration areas in the Karoo region

According to Tiplady (2011), the following conclusions were drawn:

- 1 Based on assumptions made regarding the type of equipment to be used during hydraulic fracturing operations, a buffer zone of 30 km should be adopted around each SKA station, inside which no hydraulic fracturing activities should take place.

- 2 A secondary buffer zone of 50 km around each SKA station should be adopted, inside which (i.e. between 30 and 50 km from an SKA station) potential hydraulic fracturing operations should be assessed in detail and, if required, conditions imposed prior to any such activities taking place.

The conclusions reached were limited in the following aspects:

- (i) The assessment was based on a limited understanding of the full inventory of equipment to be used, how it will be used, and supporting activities as part of a programme for site establishment, construction, operations, and decommissioning.
- (ii) The assessment was not able to consider site specific details (such as topographical shielding).
- (iii) The assessment considered the risk of EMI only in detail. The risk of RFI resulting from the use of wireless telecommunication services would be assessed in accordance with the regulatory framework implemented through the AGA Act if used anywhere within the declared Karoo central AAA. However, significantly increased usage over and above the status quo of class licenced devices (such as Bluetooth transceivers, Wifi networks and consumer communication services) in and around the area may pose significant challenges on the ability of licensing authorities to manage the risk of interference.

A degree of uncertainty was therefore considered in identifying appropriate buffer distances. This uncertainty could be reduced by undertaking the following:

- (i) Determination of the full range of equipment to be used, and supporting activities, in the site establishment, construction, operation and de-commissioning of hydraulic fracturing sites for each of the various prospective licence applicants.
- (ii) Radio frequency measurements and analysis to characterise the EMI from any relevant equipment if no appropriate national or international standards exist. This may require field work at representative sites operated by the licence applicants.
- (iii) Determination of a detailed deployment (including site selection) and operations programme, to be used as input into an impact analysis.

A reduction in the uncertainty may, but is not guaranteed to, result in a decrease in the required separation distances for protection against sources of EMI. Assessments for exact locations of hydraulic fracturing sites may also result in decreased separation distances as a result of site specific topographic shielding.

An updated assessment (Tiplady, 2012), undertaken following the SKA site bid announcement in 2012, found no justification for reducing the recommended separation distance (or buffer zone) as a result of the change in the radio frequency spectrum to be used by the SKA in South Africa.

4.3.4 Updated Assessment

As part of this consensus study, an updated assessment of the possible risks of hydraulic fracturing impacting on the SKA project was undertaken and is reported below. The current methodology that has been adopted by SKA South Africa to determine the impact of EMI and RFI sources on SKA stations is aligned with that presented in the previous reports (Tiplady, 2011; 2012). No further detailed information has been made available to SKA South Africa regarding the exact inventory of equipment, and 'use profile' (i.e. how the equipment will be used during site establishment, construction, operation and decommissioning) thereof, nor on the deployment strategy and supporting activities.

SKA South Africa has compiled a significant body of knowledge on expected emissions from potential renewable energy facilities (solar photovoltaic, solar thermal and wind turbines). Although it cannot be definitive, it is possible to draw some conclusions about emissions and radio frequency propagation from basic industrial equipment. In general, the assessments conducted support the recommendation of a 30 km buffer distance around SKA stations for hydraulic fracturing. This distance could be reduced, but only on a case-by-case basis and following detailed measurements and predictions of expected EMI and RFI from the sites and supporting activities. The scope of supporting activities is not well understood, and remains a critical risk to be mitigated through careful assessment of detailed deployment strategies (of hydraulic fracturing sites). Part of this risk lies in the potential increase of vehicle volumes along transport routes that currently only experience very light traffic volumes, and near which SKA stations are located.

In order to ensure a strong protection regime for the SKA, it is important to preserve regulatory efficiency and avoid complex authorisation processes that could result in competing interests. In that context it would be necessary to ensure that the relevant licensing authority for hydraulic fracturing is required to consider and include relevant protection requirements for the SKA as a condition on the license (or permit). Such a regulatory process ensures that no conflicting permitting conditions arise for the applicant (who may or may not require further permits from other authorities as per the AGA Act and other relevant legislation).

4.3.5 Summary

Hydraulic fracturing operations, including supporting activities, remain a significant risk to the scientific performance of the SKA. Part of this risk is as a result of the uncertainty that arises from a lack of information on specific hydraulic fracturing activities such as deployment strategies, site specific analyses, equipment usage (and characterised in terms of EMI), and supporting activities. As a result, the following proposals are made:

- No shale gas exploration or exploitation should be undertaken anywhere by any applicants within the Karoo Central AAA without formal consent from the Astronomy Management Authority, located within the DST and designated by the Minister of Science and Technology to protect declared areas in terms of the AGA Act and regulations. Such consent may include conditions and/or restrictions, which should be included as a condition on the permit/license issued by the respective authority to the applicant for shale gas exploration and/or exploitation.
- A minimum 30 km buffer distance around each SKA station beyond the Karoo Central AAA and within the Northern Cape province, is proposed. Prior to any proposed exploration and/or exploitation activities by license applicants that coincide with these buffers zones consent should be obtained from the Astronomy Management Authority. Such consent may include conditions and/or restrictions, which should be included as a condition on the permit/license issued by the respective authority to the applicant for shale gas exploration and/or exploitation;
- Prior to any exploration activities commencing, applicants for shale gas exploration in the Northern Cape province should be required to work together with the Astronomy Management Authority to identify exploration sites appropriate both to SKA South Africa and the licence application that would not pose a detrimental risk on the scientific performance of the SKA. The licence applicant shall work together with the Astronomy Management Authority to conduct suitable measurements, as required, to reduce the uncertainty of hydraulic fracturing and supporting activities as noted in this report.

4.4 Potential Socio-Economic Impacts

4.4.1 Introduction

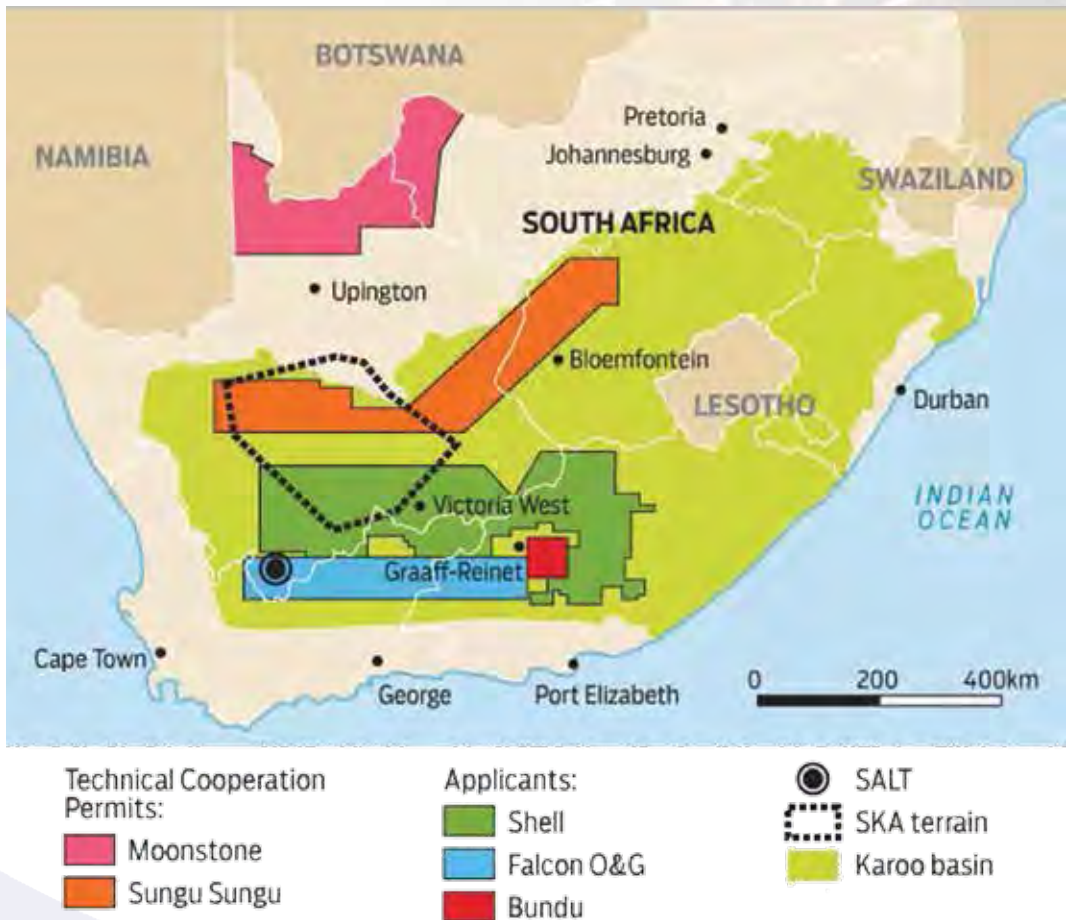
The potential socio-economic and community impacts of shale gas development on a relatively pristine natural environment such as the Karoo, and its small rural towns and farming communities, are documented in this section. In addition, since the stated economic benefits of shale gas development are a potential 'game changer' for the country, these aspects are explored within the context of what this might mean for the nation as a whole, and the Karoo in particular.

The Karoo is unique, both in global terms and in a South African context. First, it is relatively pristine, and second, it presents a new challenge to South Africa which has in general focused for more than 100 years on hard rock mineral mining, and with some experience in offshore oil and gas development since the 1980s.

4.4.2 Socio-Economic Profile and Challenges in the Central and Southern Karoo

The Karoo Basin covers six of the nine provinces of South Africa. With reference to proposed shale gas development, technical cooperation permits were issued initially across a vast area, stretching across four provinces, including the Eastern Cape, Western Cape, Northern Cape and the Free State. In February 2015, two of the existing permit holders have proceeded with the submission of their EMPs, as part of their exploration licencing in the basin. These included Bundu and Falcon (Morkel and De Wit, 2016) as depicted in Figure 4-4.

APPLICATIONS FOR HYDRAULIC FRACTURING



Source: Treasure Karoo Action Group

Graphics24

Figure 4-4: Location of the Karoo Basin and the exploration areas in relation to national provinces, as well the locations of the SALT and SKA activities (www.karoospace.co.za)

This report focuses on the socio-economic profile of the central and southern Karoo Basin; this area spans Calvinia (Northern Cape) and Laingsburg (Western Cape) in the west, to Noupoort (Northern Cape) and Fort Beaufort (Eastern Cape) in the east. There are seven district municipalities (viz. Sarah Baartman, Chris Hani, Amathole, central Karoo, Cape Winelands, Pixley Ka Seme and Namakwa), 13 local municipalities and 22 key small towns potentially affected (AEON, 2015). It is important to nuance our understanding of socio-economic impacts with a local perspective, as this is where citizens reside and experience impacts. This is also where response and mitigation measures would need to be focused in managing any identified risks (i.e. either to the natural environment or to local communities).

The Centre for Development Support (UFS) (Atkinson, 2007) has identified the socio-economic challenges confronting these areas as part of the "Arid areas of South Africa" as follows:

- *"Poverty levels are high, due to high levels of unemployment, and increasing rates of illness (HIV/AIDS and TB).*
- *Communal farming on municipal peri-urban land is creating environmental challenges.*
- *A large proportion of income is derived from social grants, with social consequences that are not fully understood.*
- *Local economies of small towns are characterised by weak multipliers, because a great deal of purchasing power is spent in the larger centres, or metropolitan areas situated outside these areas.*
- *The influx of migrants from the farms to the towns, and the migration from the more densely populated areas in the Eastern Cape towards the Karoo, are creating immense pressures on the existing infrastructure.*
- *Due to the arid nature of the area, surface and underground water supplies are insufficient to provide higher levels of infrastructure (such as waterborne sanitation), which creates grievances and resentment.*
- *The conditions of life of remote settlements of farmworkers tend to be poor, with low mobility, and difficult access to health, education, recreation and shopping amenities.*
- *HIV/AIDS levels are reputed to be high, particularly on national transport routes, and mortality rates are already reflecting this.*
- *There is an out-migration of skilled people, due to a lack of local economic opportunities.*
- *Increasing aridity, due to global warming, may lead to rising unemployment, declining underground water levels, and greater difficulties for commonage farmers."*

There are important socio-economic differences across the three provinces of the southern and central Karoo Basin that stem from historical factors. The past prevalence of homeland or 'Bantustan' administrations

in parts of the Eastern Cape and consequent contrasting land ownership patterns across the region have led to a racialised social order and the perpetuation of racial inequalities in the region (Mkhize, 2012).

There are clear class and racial dimensions to the emerging shale gas debate in the Karoo, with contrasting views held by those who own the land and draw benefit from it as a productive asset, and those who do not. There appears to be increasing support from community structures for shale gas development, with the expectation of large-scale employment and economic empowerment in an environment which until now has not promised much else, except for the agriculture sector. Evidence of this was noted in the comments raised by local community representatives at town hall meetings (hosted by the Eastern Cape Provincial Government) during October 2014, where structures such as the The Karoo Shale Gas Forum participated. This is in sharp contrast to the existence of structures such as Treasure Karoo Action Group (TKAG), and local structures of organised and commercial agriculture (such as those affiliated to Agri Eastern Cape) who have long been opposed to shale gas development in the Karoo.

In the midst of this, there are new social classes emerging across the Karoo, influenced by land restitution and political transformation since 1994. In this regard, there are the indigenous Khoisan, who have also noted the need for due recognition of their cultural, political, and land rights over the Karoo, which they consider spiritually and culturally significant. They have already declared their opposition to proposed shale gas development and are claiming stronger recognition of their land rights across the region.

Then there is the small emerging class of new black farmers, who have not yet fully integrated into the well organised and structured networks of established (i.e. predominantly white) commercial farmers in the Karoo. These are largely constituted of collective ownership models, and located on commonage farms on the outskirts of towns. Here land was purchased from white commercial farmers through programmes within the Department of Rural Development and Land Reform, or alternatively under ownership of the local municipalities and made available for farming. These rural black communal farmers are also concerned about the potential environmental impacts of proposed shale gas development on their water and land. Over time, it has emerged that this pattern of land use has been skewed by the growing concentration of land for purposes of game farming and private conservation, which has been exacerbated in part by claims of foreign and wealthy landowners amassing large portions of farmland in the Karoo.

4.4.3 Socio-Economic and Community Impacts Associated with Shale Gas Development

It is anticipated that there will be considerable social impacts, both positive and negative, and associated externality costs on the communities in the localities earmarked for shale gas exploration and production. Internationally, there is significant research documenting the socio-economic and community impacts of shale gas development.

4.4.3.1 The International Experience

Reflected across international studies is a set of similar cross-cutting potential social and community impacts linked to shale gas development (Townson University (RESI), 2013; ACOLA, 2013; Quebec BEP, 2014; Council of Canadian Academies, 2014).

Drawing from these studies, the following points contain critical lessons for South Africa. Thus there is a need:

- 1 to generate a credible and detailed, multi-dimensional and holistic understanding of the receiving environment (i.e. socially, geologically, community health, water and air quality, etc.);
- 2 for more robust and peer-reviewed data on the impacts and benefits to the macro-economy, as well as regional and local economic effects of shale gas development;
- 3 for effective and robust scientific data in driving ongoing and long-term monitoring of environmental, health, and socio-economic effects (e.g. through baseline and longitudinal studies) within local communities affected by shale gas development;
- 4 to develop an effective and transparent framework for governing and regulating the industry.
- 5 for full disclosure and open communication between policymakers, regulators, industry and the communities affected by shale gas development. In the context of the Karoo Basin this would include the need to address urgently the current knowledge asymmetries which exist amongst the various communities across the Karoo.

4.4.3.2 Potential Socio-Economic and Community Impacts and Risks in the Karoo

4.4.3.2.1 Human Health and Safety Impacts

These include potential contamination of groundwater, pollution of the surface ecology, earthquakes, air pollution and GHG emissions, and associated health risks. In addition, there are human safety risks associated with increased truck and freight movement, the effects of a transient workforce on relatively isolated communities and psycho-social impacts related to industrialisation (i.e. noise and influx).

Currently, the threat to groundwater is located within both surface and sub-surface processes of shale gas extraction. Contamination pathways have been linked to hydraulic fracturing chemicals entering into freshwater sources, as a result of fractures extending into groundwater sources and possibly along deep geological structures. However, considerable risk exists in the occurrence of flowback or produced water to the surface, and the disposal and transporting thereof, to both surface and groundwater (Zoback, Kitase and Copithorne, 2010; Zoback and Arent, 2014). This is important, when considering the number of truck loads required for moving solid and liquid materials to and from well sites (De Wit, 2011). In addition, there is growing evidence from new data showing a higher risk of contamination through inferior well-casing and weaknesses in the integrity of the concrete utilised in the construction of wells (Zoback and Arent, 2014; Department of State Development, Government of South Australia, 2015). A recent study in the US found that "gas geochemistry data implicate leaks through annulus cement (four cases), production casings (three cases), and underground well failure (one case) rather than gas migration induced by hydraulic fracturing deep underground" (Darrah *et al.*, 2014). These technological and engineering challenges on well construction, monitoring and regulation will place new demands on both industry and government regulators. However, at the surface the dangers associated with the management, disposal and transportation of 'produced water', and potential spillages, are also significant concerns which will require appropriate mitigation strategies.

International guidelines and industry best practice codes have been developed and are being included in the new regulations for hydraulic fracturing. However, it will take time for South African regulators and industry to mainstream these, should hydraulic fracturing commence. Even in the USA, there are challenges linked to their capacity to regulate the shale gas sector and associated processes such as land acquisition, land use management and leasing processes, as well as the ongoing monitoring of compliance by industry. This understanding will be critical for regulators and policymakers in considering modalities for capacitating regulation and monitoring, given the challenges of skills and expertise in the South African context.

Compounding the risks to human health associated with potential surface and groundwater contamination, are the prevailing challenges of water quality and availability in the Karoo. For the average Karoo municipality, this is a daily challenge which confronts regional water service agencies, local authorities and the communities they service. Nationally, recognition has been given to this challenge by government as a whole, and it currently enjoys sustained focus across government (National Treasury, 2013). Furthermore, there are clear signs of greater awareness and emphasis on capacitating groundwater management and monitoring through the DWS and the WRC within the Karoo.

Any threat to the sustained supply of the available potable water in the region, which is mostly arid and dependent on groundwater, will have a devastating effect on local livelihoods and is particularly relevant given the water-intensive nature of the hydraulic fracturing process. This concern requires serious consideration by policymakers and regulators, as it lies at the centre of community concerns across all sectors in the Karoo.

Alongside risks associated with water pollution are risks associated with the anticipated influx of people and the increased movement of equipment, machinery and capital into the region. The potential for an increase in incidences of crime and related social problems, such as prostitution, drug and substance abuse, along with a general breakdown in social cohesion would need to be anticipated and managed well in advance of the sector entering the Karoo.

In addition, the expected impact of intense road freight and truck traffic on the regional and access road networks, must be carefully considered. Given the existing state of affairs in many small rural municipalities as it pertains to the maintenance of critical road infrastructure, the relatively under-developed disaster management infrastructure and capability, as well as community safety (including local traffic law enforcement), it is clear that increased road traffic will pose a significant challenge for local and provincial authorities. This might require consideration of a special provincial and local government grant for areas affected by shale gas development in the future.

Mitigation and preparedness will require proactive planning and coordination across spheres of government and the relevant public health, security and protection agencies. It will also have implications for further research into the potential impacts on long-term human and animal health in the region.

4.4.3.2.2 Socio-Economic Impacts

It is important to note that, to date, both internationally and in South Africa, much of the information in the public domain has been industry-driven and has not been sufficiently tested or subjected to the rigour of scientific peer review (Barth, 2013; Wait and Rossouw, 2014).

Much of the promise of sustainable local economic growth in the Karoo, and South Africa as a whole, based on the USA experience, is still far from conclusive. Recent economic data from USA shale plays, as well as the projected impacts of the drop in global oil prices since November 2014, have brought into sharper scrutiny the hitherto dominant discourse of the 'Global Shale Gas Revolution'. It is clear from energy analysts and emerging research on the economics of shale gas development in South Africa that the economic modelling of the full extent of the overall commercial viability

and the externality costs related to prospective development of the Karoo Basin remains uncertain. This is especially relevant when considering the net effect on overall gross domestic product (GDP) contribution and employment, as well as opportunities for localised beneficiation (Wait and Rossouw, 2014; Fakir, 2015). These matters are explored in greater detail in Section 6.2.

Whilst noting the above, and in taking a cautious approach to the possibility of any positive impacts on the local and regional economies of the broader Karoo, it should be noted that the current levels of unemployment, poverty and vulnerability in most localities are severe. This is currently having its strongest effects on the most vulnerable sectors of society, namely, women, children, the youth, the elderly, and the rural poor, most of whom are historically disadvantaged, as a result of the legacy impacts of apartheid and colonial rule and patterns of ownership and economic participation, which excluded large portions of these communities from meaningful participation in the economy.

In the context of the Karoo, a common characteristic across the social and economic landscape has been the migration of skills and labour to the major coastal centres of either Cape Town or Port Elizabeth. With extensive agriculture being a significant employer of the semi-skilled and unskilled workforce in the region, the potential impacts on the agricultural sector in the Karoo are far-reaching for smaller rural municipalities. Here rapid industrialisation might ironically hold real dangers for rural livelihoods such as farm-based economic activity linked to agricultural production, and local tourism products linked to this way of life, such as conservation, eco-tourism, and game-farming and hunting operations.

In this context, the potential impact on local labour could be two-fold, namely:

- 1 Gradual and widespread job losses, and displacement of agricultural workers and their families from the land (i.e. from farms, as well as from smaller towns which are currently servicing local farms).
- 2 Even though it has been noted that the typical shale gas well site itself will not provide significant job opportunities, it is anticipated that there will be considerable employment opportunities within the auxiliary sectors, such as construction, hospitality, and the services sector, albeit that this is expected mainly during the field development phase, with minimal opportunities for localised employment during exploration and well construction phases. This is seen as a concern by those who argue that there will be a distortion of the local labour market in the Karoo, with the agricultural sector competing with higher paid wages in the oil and gas industry. At the same time it is recognised that local communities may find new opportunities arising from the development of such an industry.

Additionally, the unresolved land restitution programme of government, with its empowerment of a new class of black farmers and landowners, is also potentially at risk. In this regard, there are a number of issues that might need closer attention and consideration, within both the broader land restitution process in the Karoo as well as in contemplating shale gas development by government and industry. The political economy of land access, and acreage, will be as relevant in the context of the Karoo, with its vast expanses of land, as it is in the USA, where lease rights remains a key component of basin economics. This has the potential to be further compounded by the ongoing land restitution and redistribution programmes being implemented by government (Morkel and De Wit, 2016). Possible competition for land and the potential for competing land use with other sectors in the local economy by shale gas development must be seriously considered and further investigated. It is anticipated that the newly adopted Spatial Planning and Land Use Management Act (SPLUMA) will have a role to play in this process in the future.

4.4.3.2.3 Social and Political Risks and the Social Licence to Operate in the Karoo

The biggest challenge is the potential lack of adequate public consultation, the social license to operate and impacts on social cohesion. The challenge for government (i.e. all spheres: national, provincial, and local), its stakeholders, and local communities is to harness the necessary trust and social capital to effectively navigate the prevailing complexity and associated uncertainties linked to shale gas development in the Karoo.

This relatively pristine but isolated landscape is steeped in a deeply textured social, cultural and political history, which has an influence on what has been referred to as "The great shale debate in the Karoo" between those seeking to maintain a pristine Karoo and those who see Karoo shale as an opportunity to transform the existing economic power relations in the Karoo (De Wit, 2011). However, as recent public engagement sessions have revealed, this debate is not as polarised as reported and projected in the media. The debate is now more nuanced, with communities on both sides of the debate being galvanised around a broad range of issues and interests. Similarly, a review of recent comments from Interested and Affected Parties, registered during consultations between exploration companies and local communities during February 2015, revealed a significant concern with the regulatory and monitoring capacity of the state to effectively oversee and govern shale gas development in the Karoo (Morkel and De Wit, 2016).

However, in the South African context, this debate cannot avoid the ever-present narrative of possession and dispossession, especially between those who own large tracts of Karoo land and those who were historically removed from the land; a divide that exists predominantly along racial lines.

Recent public consultations, conducted by provincial government and industry with local communities in the central and southern Karoo, have noted an absence of key national departments and agencies within these receiving communities; local consultation has been left largely to industry, as part of their compliance processes, under Section 10 of the MPRDA.

This is happening in stark contrast to how the DMR has traditionally operated within communities where hard rock mineral extraction is taking place, and might be linked to the lack of institutional coherence and readiness of the shale gas sector to effectively regulate the complexities of shale gas development in the Karoo, and other traditionally non-mining intensive regions of the country.

Similarly, there is the existing mandate of, and capacity within, PASA for consultation and community engagement in the context of an emerging shale gas industry. Traditionally, the focus has been offshore and we are entering into uncharted territory with regard to shale gas in the Karoo. What is possibly required is the presence of a public interest voice, independent of industry and other sectional interests. Here the emphasis should be on knowledge sharing, and addressing the prevailing asymmetries in this regard. This might very well require a coordinated government approach to communication and information sharing across the various spheres of government (national, provincial, and local), through which communities are engaged, informed, and empowered through an appropriate programme of information sharing and development communication.

4.4.3.2.4 Governance and Institutional Impacts

Underlying this category of risks are the anticipated impacts of externalities associated with shale gas development in small rural municipalities, many of which are already challenged with weak and inadequate social and economic infrastructure, skills and capacity, and are currently unable to effectively manage the expected importation of risks and exportation of benefits typically associated with shale gas development.

Inter-governmental coordination and streamlining of functions between the three spheres of government are essential, and has not yet been proven adequate either to address both current weaknesses at the 'zone of impact' (i.e. where development and service delivery occurs), or to provide a sufficiently integrated regulatory and monitoring framework for activities at the 'critical zone' (i.e. where mining and mineral extraction occurs) in anticipation of shale gas development in the Karoo. Whilst the new MPRDA Technical Regulations for Petroleum Exploration and Development (which are derived from the American Petroleum Industry (API) standards) were adopted by the DMR in June 2015 such interventions may not be adequate. It will be of critical importance to ensure the

development of adequately trained personnel with the necessary skills to enforce the regulations as this is a new extractive industry for the country, and will be completely foreign to the receiving environment of the Karoo (Morkel and De Wit, 2016).

In terms of new thought leadership, considerable emphasis is being placed on both the vertical and horizontal coordination across government. This is also aligned to the growing global recognition of the need for effective legislation, and regulatory frameworks for monitoring and mitigation of potential risks associated with the sector. In addition, the need for assessing and capacitating government and society as a whole to better assess, quantify and ultimately manage, both the concomitant externality costs and opportunity costs, of pursuing shale gas development as a country.

In the current context of the Karoo, it is uncertain if the process to date reflects this growing consensus approach to shale gas development. In particular, the gap between ongoing and wide-reaching legislative and regulatory reforms by government (i.e. in response to shale gas development) and the absence of an appropriately wide-reaching public consultation and awareness programme in the Karoo.





5 RATIONALE AND METHODOLOGIES FOR SHALE GAS BASELINE STUDIES



One of the most important early interventions that will need to be undertaken prior to the launch of a shale gas industry is a comprehensive set of baseline studies in order to ascertain the conditions currently prevailing in the region of the Karoo where shale gas activities may take place.

5.1 Introduction

The anticipated exploration and exploitation of Karoo shale gas through hydraulic fracturing have raised considerable debate about the benefits and risks associated with this process both for the Karoo, and the country as a whole. Focus has been placed on, *inter alia*, the potential impacts of hydraulic fracturing and shale gas harvesting on ecological and other natural services, on scarce water resources, on socio-economic and community issues (Figure 5-1). Risks associated with these potential impacts deserve careful and accurate evaluation and monitoring.

Essential to the sustainable development of any long-term monitoring system of impacts and risks is the need for the acquisition of (natural) baselines: an understanding of the existing framework prior to the introduction of an intended intervention or critical process related to exploration/exploitation. A baseline study would enable the establishment of a body of knowledge and relevant information on key attributes or characteristics prior to the commencement of prospective exploration/exploitation for shale gas in the Karoo, and without which defence of possible litigation against improper practices may prove almost impossible.

Shale gas resources represent a critically important transition fuel on the path to a decarbonised energy future. However, in the context of sustainable management of this relatively unconventional resource, and for benefits of shale gas to be realised by all, it is essential that if it is developed, it is with effective safeguards to mitigate risks on a large number of complex interrelated issues linked to water resources, air quality, ecosystems, and societal needs.

Across the Karoo, it is particularly important to protect shallow aquifers from contamination. This may depend on, but is not limited to, the availability, quantity, transport, and treatment of potential flowback and produced waters as well as pollution of local shallow, freshwater aquifers

and surface environments via underground gas and chemical leakage. Therefore, aquifer baseline studies in the Karoo ahead of gas exploration are essential.

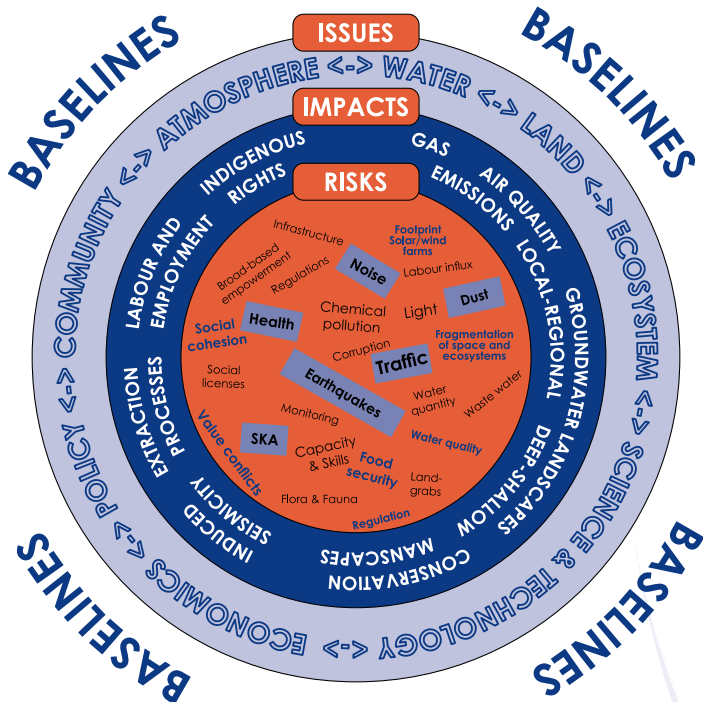


Figure 5-1: Interrelated issues and impacts associated with shale gas development (Modified for the Karoo from Zoback and Arent, 2014; Morkel and De Wit, 2016)

Shale gas developments have consistently shown that hydraulic fracturing itself is apparently not the direct source of contamination, but that this appears to be mostly the result of poor well construction or poor drilling practices and careless waste management. Many operational issues therefore require close attention, particularly to enforce proper well construction. Another water issue associated with shale gas development involves the disposal of wastewater flowing back from the shale formation after hydraulic fracturing. Flowback water typically contains large amounts of salt, various quantities of selenium, arsenic, small amounts of NORMs, as well as deep formation bacteria, all of which may come from the gas-producing shale formation and will contaminate local surface systems and subsurface soils (critical zone) if allowed to escape. Thus, ecosystem and critical-zone baseline studies in the Karoo before gas exploration are essential.

Another environmental issue of concern (and debate) is related to the life cycle of carbon emissions and thus gas emissions that occur during drilling, hydraulic fracturing, well production, and natural gas transmission

and distribution (e.g. MacKay and Stone, 2013; Heath *et al.*, 2014). The gas is mostly CH₄ which is a more effective GHG than CO₂, and therefore CH₄ leakage at well sites (fugitive emissions) could offset the significant advantage of using natural gas over coal for producing electricity. If CH₄ emissions during shale gas extraction and use can be restricted and controlled, this would provide a much needed reduction in South Africa's GHG emissions. In addition, because the use of natural gas to generate electricity produces negligible NO_x, SO_x, and Hg (mercury) particulates, switching from coal to natural gas would lead to significant and immediate health and quality of life improvements. Thus (natural) CH₄ leakage and air quality baseline studies in the Karoo before gas exploration are essential.

There is an apparent association between shale gas development and a marked increase in seismicity. It has been known since the 1960s that the increase in pore pressure that results from fluid injection may cause seismicity by decreasing the normal stress on potentially active, pre-existing faults. Since the pore pressure changes at depth during hydraulic fracturing are quite small compared to the ambient stress, the pore pressure can be thought of as triggering the release of stored elastic strain energy resulting from natural geologic processes over time. In effect, the pore pressure increase from fluid injection advances the timing of a potential earthquake that would someday have occurred as a natural geologic process. Hydraulic fracturing operations very rarely trigger earthquakes large enough to be felt by humans, principally because pressurisation affects a relatively small volume of rock for a short period of time (a few hours; Ellsworth, 2013). However, wastewater injection wells operate for years, sometimes injecting large volumes of wastewater that could affect large volumes of rock over large areas, and could induce a significant earthquake (McGarr, 2014; Hornbach *et al.*, 2015; Witze 2015). Thus, micro-seismic and structural geology baseline studies in the Karoo before gas exploration are essential, and thereafter, induced seismic maps must be developed for the Karoo.

Over and above these environmental studies, there is the need for better socio-economic baseline studies related to potential benefits and risks of shale gas extraction in context of the lack of social cohesion and potentially disruptive engagement linked to the present wide-spectrum of differential incomes, opportunities and ownership of Karoo stakeholders. If shale gas is to displace other forms of energy for heating or electricity generation, and encourage local entrepreneurship, robust socio-economic studies are needed at all scales and social-levels. Thus, a comprehensive socio-economic database for the Karoo needs to be compiled now.

5.1.1 Background

Geologically, the Karoo Basin covers about half the total surface area of South Africa (0.7 million km²), and just over half of that covers the relatively

dry and impoverished geographical Karoo, with a globally unique biodiversity, across parts of the Eastern Cape, Western Cape, Northern Cape and Free State provinces of South Africa.

To develop an effective environmental monitoring programme based on sound knowledge of the present *status quo*, it is first necessary to review and synthesise existing data and knowledge, including indigenous knowledge of the San/Khoisan, local communities and farmers.

Thereafter, early baseline research should be focused on measurements at scientifically selected sites anticipated to be hydraulically fractured and also compared to areas away from potential well-sites. A data time series of environmental indicators at critical zones must be developed to manage risks, benefits and uncertainties of gas exploitation in the Karoo.

5.1.2 What in the Karoo is Foremost that must be Protected?

The Karoo has an arid climate, with only 200 - 400 mm average annual rainfall (but which increases towards the easternmost Cape (800 - 1000 mm)); groundwater boreholes form the sole source of water supply to many communities, small towns, farms and other users. In many cases, replacing this groundwater source would be impossible, since surface water sources are largely ephemeral. There has been considerable research into groundwater in the Karoo Basin over the years, although relatively little has been done in the south-eastern part of the basin, where most people live and where there is high demand for water and sanitation. Groundwater in the Karoo is believed to flow rapidly through the predominantly fractured aquifers, with little 'filtering' or attenuation of contaminants. Thin or absent soils further add to the risk of surface contamination

The Karoo geology and hydrogeology associated with igneous (magma) intrusions (now dolerite sills and dykes), and fault/fracture zones, are poorly understood, and are virtually unmapped at depths below 150 m, except along only three modern deep geophysically imaged profiles across the south of the basin, and limited shallower profiles on the high plateau north of the escarpment, as well as some 20-odd deep rock-cored wells drilled by SOEKOR in the 1960s and 1970s (several up to 4 km deep). In addition, at least one intraplate fault system (Ceres-Tulbach) along the southern edge of the Karoo Basin is known to be seismically active to a depth of 15 km (Smit *et al.*, 2015).

The high temperatures of the igneous intrusions (>1 000°C) followed by their cooling, during which shrinkage fractures form, are known to have had a considerable impact on gas escape from the shales in the deep geological past, and which may have reduced their gas potential (Svenson *et al.*, 2007; 2012; Chere, 2010; 2015), yet today the intrusions still act as local water traps and channels (Aarnes *et al.*, 2010; 2011). This still needs to be quantitatively evaluated.

Karoo sedimentary rocks generally have low primary porosity and permeability, with exploitable groundwater storage and flow occurring in openings such as fractures, faults, margins of intrusive bodies, and bedding planes. Although borehole yields in the Karoo are generally less than 5 l/s, anomalously high-yielding boreholes are located on such structures and provide most of the region's water supply.

Most existing water boreholes in the Karoo are less than 150 m deep, but the occurrence of deeper groundwater is thought to be a possibility in several areas, particularly associated with certain types of dolerite intrusions. Deeper groundwater (more than about 500 m deep) is generally saline and upward-flowing, as evidenced by the hot springs found at several locations in the Karoo, and imaged using deep geophysical techniques (e.g. Branch *et al.*, 2007; Weckmann *et al.*, 2012).

Groundwater quality from existing boreholes is generally potable, with TDS concentrations in the range 500 - 1 000 ppm (seawater has approximately 35 000 ppm). The TDS fluctuates, however, due to the generally low but episodic recharge occurring in the arid climate, and is brackish in some areas, suspected to be due to upward flow of deeper saline groundwater. The rates and degrees of these flows are not known.

The greatest concern is that during and following hydraulic fracturing, which essentially produces a significant number of micro-earthquakes, enhanced induced upward flow of saline groundwater and/or hydraulic fracturing fluids could severely contaminate scarce groundwater sources via defective gas-wells and/or naturally occurring fracture zones that may be reactivated during fracking-induced micro-earthquakes, as well as from spills and leaks on the land surface due to accidents and poor work practices. Whilst reuse of flowback water for hydraulic fracturing and subsurface storage are currently addressing concerns regarding the salt quantities that are brought to the surface, such reuse and storage also requires stringent regulations and monitoring capacity.

Exploration for, and subsequent harvesting of shale gas is therefore of considerable concern to the stakeholder communities who fear that deep drilling and hydraulic fracturing will contaminate their groundwater resources, and that they will not be able to obtain compensation.

5.1.3 International Perspectives

In a broader global perspective, there is a growing interest for baseline studies in the Karoo, because this basin is one of few with potential unconventional reserves of gas that has not yet been contaminated by extensive exploration through deep drilling and hydraulic fracturing. As such, and most importantly for the present purposes, the Karoo represents the best natural state of play for basins, globally, for scientific baseline

studies and related regulatory and legislative purposes, but only if completed before it becomes disturbed through intrusive exploration and exploitation practices. It is likely therefore that there will be global interest in the results of Karoo baseline studies even prior to exploratory fracking.

It is imperative also to understand that all this must proceed within a framework of a dynamic field. The hydraulic fracturing technology is rapidly improving, and it is likely that hydraulic fracturing will start within the next five years, leaving only a small time window for robust natural baseline studies. In this context, it must be emphasised that the technology and most equipment required for virtually all efficient scientific baseline studies, and continuous monitoring thereafter, is generally not presently available at South African academic research institutions or at its science/research councils. Furthermore, there is minimal expertise at our universities in unconventional gas upstream exploration. These are the first hurdles for Karoo baseline studies, and subsequent monitoring, if they are to be carried out using independent, local expertise (e.g. Mair, 2015).

5.2 Time Frames

There is perhaps a five-year window of opportunity ahead of the start of potential hydraulic fracturing to gain a firm understanding of the natural underground water systems and surface environments, which could be used to establish a forensic baseline across the Karoo. Without such a baseline, underpinned by a good understanding of the hydro-geology/geophysics, any contamination or destruction of groundwater and ecosystems related to hydraulic fracturing and harvesting of gas cannot be determined with sufficient accuracy or proven beyond reasonable doubt, rendering litigation around damage and externality costs of exploitation of the gas almost impossible.

Water management for unconventional shale gas extraction is one of the key issues that will dominate environmental debates surrounding the shale gas industry. To avoid retrospective externality costs such as those that have emerged directly from mining activities elsewhere in South Africa (e.g. acid mine drainage), there is an urgent need in the Karoo for comprehensive risk assessment and regulatory oversight for spills and other accidental discharges of wastewater to the environment. As gas well fields mature and the opportunities for wastewater re-use diminish, the need to find alternative management strategies for this wastewater will likely intensify and focus on its injection back into the gas-shales or into deep saline-water reservoirs, albeit with increasing potential risks of induced earthquake activity along deep fault systems (e.g. Walsh III and Zoback, 2015). Of further concern is that South Africa has presently neither the monitoring capability nor the regulatory or the enforcement capacity to provide any sense of security to citizens that extraction of shale gas would not cause long-term environmental damage.

5.2.1 Immediate Baseline Needs

From 2016 onwards, a shale gas exploration phase will commence in the southern Karoo and will last at least five years. It will include EIAs, shallow and deep geophysics imaging, and up to 20 deep exploration drill-holes. Determination of whether the gas can be economically extracted will later require hydraulic fracturing. At the time of finalising this report, the moratorium remains in place on employing this technology in the Karoo.

The design and implementation of a multi-disciplinary research programme to determine the natural and social state of the Karoo prior to the commencement of exploration and exploitation of shale gas is required. These are the so-called baseline studies. Such a study must include the following:

- **Surface water, groundwater/aquifer monitoring and analyses** to determine the natural chemical variability of water across the Karoo, as well as determining the quality and quantity of underground water reservoirs and water flow. Such targeted groundwater and gas baseline studies must be carried out in pilot areas for roll-out to other areas.
- **Micro-earthquake detection and deep-subsurface imaging studies of the Karoo** to determine the natural seismic activity, ambient noise and stresses, and variations in levels of tectonic stability across the region and to determine the structure and fault systems of the subsurface and fluid (water, gas) pathways beneath the Karoo.
- **Studies to image the 3-D geology of the Karoo** to determine possible variability of saline water resources and identify shale gas and radioactive hotspots.
- **Gas flow detection studies** to develop a point source map of natural gas-leakage (methane and carbon dioxide) sites in the Karoo, as a baseline against which to measure any occurring gas-leakage during operations around drill and fracking sites, as well as at potential future gas-wells.
- **Variations of surface and critical zone (soils) ecosystems** to monitor their natural long and short-term variability and to model potential effects of disaggregation on the landscapes and other natural life-support systems.
- **Geology and geo-engineering analyses** in order to maximise our understanding of the geology, geophysics, hydrogeology and biogeography of the southern Karoo and to determine rock and soil properties and palaeostress systems and erosion rates. The focus in the first instance should be on the most likely gas exploration areas based on available information. This may include using expensive drilling by

exploration companies for research purposes. It should also include the development of a 3-D image of microseismic events in the Karoo and surrounding regions.

- **Controlled drilling and geo-engineering experiments** through a rural 'Karoo Shale Gas Experimental Laboratory' to scientifically test and model induced seismicity, fracturing, and flow of gas-water-chemicals using a controlled single well, multi-directional hydraulic fracturing site.
- **Socio-economic assessments** to provide robust economic evaluations of the potential impact/risks of developing shale gas in terms of land value, agriculture, job creation, socio-economic development and downstream effects of gas as a manufacturing industry. This must include developing capacity through Karoo community participation in groundwater monitoring and water analyses. Every effort must be made to encourage large community buy-in for database sharing and decision-making regarding the exploitation of shale gas and to ensure an understanding of the resilience of Karoo hydro and eco and agriculture systems. These interventions will assist in developing baseline knowledge and open source database management of groundwater of the Karoo Basin.
- **Monitoring the health and well-being of humans and livestock** to determine potential effects of social disruptions and unexpected externalities.

All of the above interventions are at risk unless the appropriate skills are available to carry out such studies. To that end it may be necessary to establish (a) centre(s) of excellence in areas such as groundwater research. Such research will be complemented by developing advanced 'in-practice' graduate/diploma courses in, for example, applied hydro-geology, shale gas exploration and groundwater monitoring.

Data-base management and numerical modelling abilities will be needed to enable growth and sharing of baseline knowledge through access to open source database and to enable multi-variate testing of changes to the natural state of the Karoo Basin. Such information will also contribute to providing advice to government about the scientific and socio-economic findings in order to enhance the quality of regional and national policy planning.

Baseline research programmes must cover a wide range of interactive scientific projects, including, but not limited to:

- Geosystems
- Soil systems
- Ecosystems

- Seismicity
- Water quality
- Gas sources and leakage detection
- Shallow and deep geophysics
- Drilling and geo-engineering
- Socio-economic issues
- Legal and rural engagement issues
- Risk analyses (including potential human and livestock health-related externalities)
- Numerical modelling and data base management.

The research programme should involve the deployment of state-of-the-art instrumentation for scientific monitoring, analysis and decision-making in:

- Methane, ethane, propane, butane and helium gas/isotope detection
- Groundwater/water-well chemistry (organic and inorganic)
- Hydrology network mapping and dating the age of water
- Ecosystem changes (plants, animals, soils)
- Geology/rock properties
- Geophysics/subsurface imaging geophysics (magnetic, gravity, nuclear magnetic resonance and magnetotelluric surveying)
- Detecting micro-seismicity and ambient noise
- Training/citizen science employment in rural areas and municipalities.

5.2.2 Baseline Details for Long-Term Needs

The anticipated exploration and exploitation of Karoo shale gas have raised considerable debate about the long-term benefits and risks associated with this process for both the Karoo, and the country as a whole. Attention must be paid to the way risks scale up, and to the mechanisms to share information, learn from and adapt operational best practice, and allow cautionary approaches and effective managing of risks that can inform continuous debate (Mair, 2015). To date, most focus has been placed on the potential impact of hydraulic fracturing (which generally lasts less than six months at any one site but which may be re-fractured anytime within eight months to six years after first production (Collins, 2015)) of Karoo gas-shales on the ecological environments, landscapes and 'built environment' (e.g. agriculture, infrastructure and mining- induced), and especially water resources.

One of the most intensive debates of shale gas development is the possible contamination of potable water. These impacts have been linked to the following risks associated with shale gas extraction and hydraulic fracturing in the Karoo, namely:

- 1 Water demand may exceed the needs of agriculture, ecosystems and human consumption.
- 2 Groundwater and surface water quality may be compromised through:
 - a) spills and leaks of chemicals and/or fuels on and around the well pad;
 - b) improper disposal of returned frack-fluid and production water;
 - c) contamination of groundwater by drilling fluids and gas through faulty drill casings, poor cementing, as well as the associated risk of saline water contamination of fresh water sources through these casings;
 - d) upward and lateral leaks of highly saline groundwater into shallower fresh water aquifers via geological structures along dolerite sills and dykes, faults and fractured zones (all prominent geological features of the Karoo along its northern and southern prospective margins, respectively); and the possible regional shape of the basin that may induce artesian flow;
 - e) induced fluid flow during seismic activity along dormant faults triggered by the drilling, hydraulically fracturing or subsurface wastewater disposal.
- 3 Land use and habitat fragmentation of Karoo ecosystems and their services will result from:
 - a) well pads and increased local truck traffic;
 - b) supporting road and pipeline infrastructure;
 - c) increasing technical and social service industries.
- 4 Air quality will be affected through gas and particle emissions into the atmosphere during drilling and from poor well construction and transmission with potential direct effects on the SKA, and indirectly on local health and global climate change.

Therefore, essential to the development of any long-term monitoring system is the need for the acquisition of a natural baseline: an understanding of the existing situation prior to the introduction of an intended intervention or critical process. Essentially, a baseline study enables the establishment of a body of knowledge, or relevant information on key attributes or characteristics of any given situation prior to the commencement of prospective exploration/exploitation of the Karoo shale gas basin in South Africa.

Questions for baseline studies should be addressed through best practice and expert knowledge, and include: when and how baseline studies should be conducted, where should they take place, and how results should be communicated, including determining:

- What regional geologic features might determine 'sweet spots' for gas exploration/exploitation?
- What regional and local faults should be monitored for microseismic events?
- Which groundwater wells or water systems should be monitored?
- What time-scales are needed for results to cover drought cyclicality and spatially variable weather patterns?
- What results will provide best information about site-specific pollution (potential extraction sites, rural and urban sites)?
- What lasting changes to shallow and deep saline groundwater systems can be determined around selected old (1960s) deep drill sites of SOEKOR and previous uranium exploration-sites?
- What is the state of health (human and livestock) related to natural geochemical anomalies (medical geology)?
- What scientific techniques and equipment will produce the most robust and consistent data?
- What are the best ways to engage with local communities and provide open access to scientific data?

Central to the rationale for this Karoo baseline study remains the need for effective monitoring during and long after hydraulic fracturing. This will allow accurate future monitoring of relevant environmental, ecological and technical changes in the Karoo Basin if hydraulic fracturing and full development of the gas field commences.

In this context, the rationale for a baseline study (which importantly should not be confused in any way with an EIA or feasibility study) is inextricably linked to any future monitoring of the possible impact of gas exploration and exploitation in the Karoo Basin. Concomitant with this is the inevitability of the regulatory interface with this relatively new process of extraction, through an effective monitoring system, which will ultimately be dependent on quality, and on robust and relevant monitoring data. This system will require ongoing gathering, analysis and reporting on results over time. However, without baseline information, as is the case currently, future monitoring and effective regulation of shale gas exploration and exploitation in the Karoo will be virtually impossible. This will hinder government's ability both to legislate, and to further sanction and prosecute offenders.

Similarly, a Karoo shale gas baseline study should go beyond the establishment of a technical baseline of the geological and hydrological characteristics of the Karoo Basin. It is also important that the baseline is able to assist in long-term monitoring of the anticipated broader social and economic change. In this context, the baseline must assist ongoing monitoring and implementation of future socio-economic development outcomes aligned to the development of Karoo shale gas that are to be implemented by both government and industry. Here a baseline

study will assist in developing an appropriate 'theory of change' for the achievement of identified social and economic outcomes (i.e. defining the intended outcomes, and how these are to be achieved). Second, it will be essential for monitoring change, and improvements in the *status quo* over time, whilst later enabling effective evaluation of outcomes and impacts in the long term.

An initial three to five year 'National Karoo Shale Gas Research Baseline Programme' should be initiated prior to the commencement of hydraulic fracturing in the reservoir rock. It must be a cross-disciplinary programme comprising, but not restricted to, at least eight core research projects outlined in Appendix 3.

5.3 Focus on Dynamic Water Baseline Studies

Shale gas extraction is a water-heavy process (See Section 4.3). The amount of water required depends on the size of the exploited area, the well depth and the geological characteristics of the formation. Excessive water usage will negatively impact the local biodiversity and ecosystems, lower the water table, and as a result reduce the availability of water for local communities and agriculture. The Karoo region is highly dependent on fresh groundwater as an important water resource and with anticipated climate change it will become increasingly so. Sustainable groundwater management is thus of prime importance.

5.3.1 Reasoning and Implications

Central to the rationale remains the need for effective monitoring of groundwater during and after hydraulic fracturing commences.

Although there have been numerous studies on shallow groundwater sources within the Karoo, through the WRC, limited studies have characterised these groundwater sources based on their hydrochemistry, giving these sources an indicative and baseline signature.

Furthermore, very limited knowledge exists of the interaction between deeper contaminant sources and shallow groundwater resources. This is a potential environmental risk with shale gas development and must be considered a relatively greater risk in the Karoo due to the fractured nature of Karoo formations, as well as the presence of dolerite intrusions that could serve as preferred flow pathways for contaminants between deeper and shallow groundwater sources. Wastewater is another concern. If wastewater is improperly disposed of seepage may occur into groundwater. On average, about 30 - 60% (although this can be as little as 10% and close to 100%) of the slickwater that is pumped down the well returns to the surface (as flowback water/production water) together with the gas during production. Depending on the shale type, the water

may be extremely saline. Plant germination and growth will be inhibited by saline water.

5.3.2 Problem Identification

The following water risks are associated with shale gas extraction and hydraulic fracturing in the Karoo:

- Water demand may exceed the needs of agriculture, ecosystems and human consumption.
- Groundwater and surface water quality could be compromised through:
 - Spills and leaks of chemicals and fuels on or around the well pad due to accident, negligence, faulty tanks and equipment, flooding and over-topping of waste pits, including blowouts from the well. These are likely to show up fairly quickly in surface water sources, but also contaminate groundwater.
 - Leaks of drilling muds and associated chemicals from the well into the shallow groundwater either directly during drilling or via faulty casing/cement seals.
 - Improper disposal of returned frack-fluid and production water from the shale formation (produced water), by for example, spraying it on roads, discharging onto land surface or into dams, streams or rivers.
 - Upward leaks of highly saline groundwater from depth into the shallow groundwater through stimulation of natural geological structures, or via cracked, corroded or fractured cement, well-lining or country rock surrounding the exploration wells. This may not happen immediately.
 - Leaks of slickwater, gases and/or brines from the exploration well into the shallow groundwater caused by faulty casing/cement seals.

As surface water and shallow groundwater are usually interconnected, all the above risks apply equally to surface water. Many of these risks can be minimised by careful practices, but not necessarily eliminated.

Without upfront baseline water quality through (geo-bio) chemistry and biological data from each borehole/water source, followed by adequate and ongoing detailed groundwater quality monitoring, surface or sub-surface leaks may not be detected timeously, or at all, prior to contamination being discovered.

However, a once-off collection of baseline data will not provide timeous indication of contamination or water level changes, and will not be sufficient to demonstrate cause and effect in a court of law because of the substantial natural variations in both groundwater level and quality that occur in the Karoo due to the marked variability of the climate/rainfall from periods of drought. Data must be collected over at least two and preferably four or more annual hydrologic cycles, and should include a flood period. This serves as a word of caution to those who may rely on single sample baseline studies in the Karoo (e.g. CANSA, 2015). Early biological warning systems should be developed based on, for example, rapid turnover in distinct algae and bacterial species that may characterise changing habitats.

Because the number of water wells in the Karoo is very large (tens of thousands), a water baseline project must also seek to put in place the cheapest, most effective means of groundwater quality monitoring to allow timeous detection of adverse impacts from any contaminant source, thereby providing an essential tool for management and protection of groundwater resources in the Karoo. The project must also seek to:

- Provide accredited training of currently unemployed suitable women/youth in the skills necessary to undertake regular high-quality water sample and data collection, as well as installation and maintenance of down-hole data-loggers.
- Educate, empower, unite and assist all members of the Karoo communities in understanding and protecting their groundwater resources, thereby optimising its use, and inculcating a sense of local stewardship and ownership of local water resources.

The overall objectives are to collect the necessary baseline and ongoing monitoring data necessary for the protection and early detection of groundwater resources from potential contamination by gas exploration, mining or other activities, and to minimise the cost and maximise the effectiveness of groundwater data and sample collection, plus necessary weather data, in the Karoo, using community participation, thereby also helping to improve the understanding and management of groundwater resources in the Karoo.

5.3.3 Methodology

- 1 Review hydro-geology and existing groundwater data around early exploration determined 'sweet spots' to identify the hydro-geologically important boreholes from which approximately ten should be selected for installation of data-loggers to measure water level and conductivity at 10-minute intervals. Changes in groundwater levels and/or chemistry at the boreholes would provide information on how the

local groundwater regime operates, and feed into a larger Karoo groundwater "model".

- 2 Provide farmers, municipalities and borehole owners with an independent and low-cost means of getting their groundwater chemistry (and/or biology) checked so as to timeously identify adverse changes which can then be investigated. Even though there is no currently agreed set of chemical constituents in hydraulic fracturing chemicals or deep saline groundwater, advice from groundwater practitioners and academic studies indicate that determination of the following analyses in groundwater samples will provide sufficient initial baseline coverage: on-site electrical conductivity, pH, NO_3^- , alkalinity and CH_4 ; laboratory redox, TDS, Br, DOC, DOX, BTEX, major anions and cations, trace elements B, Ba, Cu, F, Fe, Hg, Li, Mn, Ni, NO_2^- , Pb, Sc, Si, Sr, U, Zn.
- 3 Introduce portable CH_4 and carbon isotope instruments for measurement of $\delta^{13}\text{C}$ in both CO_2 and CH_4 , essential for determining the source of the CH_4 as thermogenic (deep gas) or biogenic (shallow bacterial gas). Similarly, measurements of concentrations of isotopes of nitrogen and oxygen will become increasingly needed.
- 4 Select and train particularly unemployed, disadvantaged local youth/women as groundwater monitoring technicians to install, operate, maintain down-hole water level and electrical conductivity loggers, and in taking high-quality groundwater samples.
- 5 Develop a Groundwater Monitoring Diploma as a recognised qualification which would enable these monitoring technicians to be employed, or self-employed, collecting groundwater samples and installing and maintaining loggers in the future.
- 6 Hydro-chemically characterise both the shallow groundwater (<300 m) and deeper saline groundwater (>300 m) in the area most likely for early shale gas exploration in the Karoo.
- 7 Test the possible natural hydraulic connectivity between the shallow and deep aquifers, particularly in those areas where dolerite intrusions, as well as fault systems, may act as conduits for the preferential flow of water.

5.3.4 Details of Analyses and Interpretation

Very little detailed information exists about which determinants should be analysed for a baseline groundwater study, with respect to shale gas development. A defined provisional list of determinants which covers all groundwater user quality requirements must be set up to provide a defensible record of pre-drilling quality in the event of later claims, following

internationally accepted methodologies. The initial baseline monitoring protocol needs to include a wide selection of chemicals, chosen because they relate to the potable use of groundwater, livestock watering, natural groundwater quality, and shale gas exploration activities. Whilst several of these chemicals are likely to be present in both shallow and deep groundwater, it is still possible to derive indicative tracer chemicals for the respective groundwater sources (e.g. Figure 5-2). In addition, simple dyes (chemical tracers) should be used for tracking and detection by 'citizen scientists'.

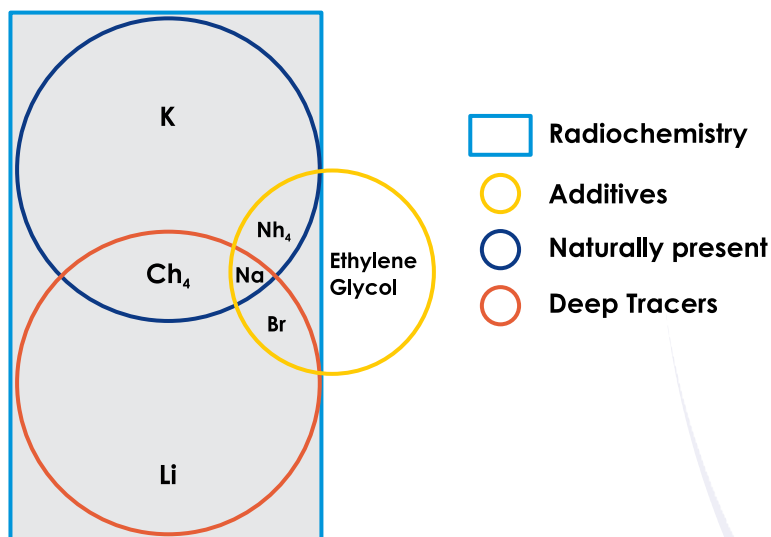


Figure 5-2: Relationship between determinants from different groundwater sources (Modified from O'Brien *et al.*, 2013)

Distinctive geochemical fingerprints exist in both shallow groundwater and deeper saline waters. Lists of indicator determinants to distinguish between shallow and deeper groundwater include: major and trace elements such as Br, Cl, Na, Ba, Sr, and Li, and radiogenic and light stable isotope ratios ($^{87}\text{Sr}/^{86}\text{Sr}$, $^2\text{H}/\text{H}$, $^{18}\text{O}/^{16}\text{O}$, and $^{228}\text{Ra}/^{226}\text{Ra}$, $\delta^{11}\text{B}$, $\delta^{13}\text{C}$, $\delta^{15}\text{N}$).

Methane $\delta^{13}\text{C}$ and Methane $\delta^2\text{H}$, as well as $\delta^{18}\text{O}$ values must be used as indicator to distinguish between shallow and deep groundwater. In the past, this has been attempted in the Karoo but without the above requirements, results have been inconclusive (e.g. Talma and Esterhuysen, 2013; 2015).





6 EVALUATION OF SOUTH AFRICA'S TECHNICAL READINESS TO SUPPORT A SHALE GAS INDUSTRY

– FACTORS TO BE CONSIDERED IN THE PRODUCTION PHASE



Chapter 4 addressed South Africa's technical readiness to support a shale gas industry in the pre-production phase. This chapter sets out to address matters relating to the production phase, such as technical challenges associated with ensuring best practice in terms of well construction and closure, distribution and exploitation of shale gas and the need to develop a significant cohort of appropriately skilled people to service this industry. The contents of this chapter should be seen as highlighting issues that should arguably be considered when the production phase commences and is not intended to provide a prescriptive analysis of how these issues should be addressed. It can be assumed that addressing issues related to well construction and closure, distribution and exploitation of shale gas and skills development will be a joint venture between the appropriate government departments and the developers.

6.1 Well Construction and Closure

6.1.1 Introduction

General problems related to the drilling process of well construction are discussed here and options presented on how to mitigate or at least how to minimise these problems.

From an operational perspective, hierarchy levels that are relevant for efficient exploitation of a shale resource are: 1) the field level, and 2) the well level.

- 1 On the field level, the exploration phase is distinct from the development or the production phase. The purpose of the exploration phase is mainly data gathering. This can be achieved by requiring companies to shoot seismic surveys, drill exploration wells, with extensive logging and coring programmes, and/or perform hydraulic fracturing treatments. As soon as the regulator receives these data, development scenarios can be modelled and beneficial production license agreements can be issued. The development or production phase requires finding ways for efficient exploitation and optimisation of production and operations. This phase for shale gas is similar to a large-scale manufacturing process over a large area.

2 On the well level, the various phases are:

- Planning: Well trajectory planning, water management plan, etc.
- Site preparation: For each well for single well pads and only once for all wells on a multi-well pad.
- Well construction: Drilling of the well.
- Completion: Installing the completion string and preparing the well for stimulation treatment.
- Stimulation: For shale gas hydraulic fracturing, treatment with water-based fracturing fluid (CO₂ or propane treatments, instead of water, are occasionally applied).
- Flowback: A fraction of the injected water flows back to the surface.
- Production: Production of hydrocarbons and produced formation water.
- Well closure: Cementing and plugging of the well.

In order to put the problems specific to South Africa into context, a base scenario for potential development is presented. Similarities to the USA, which is currently the biggest shale gas market in the world, are considered to suggest meaningful numbers for South Africa's situation. The size of the Karoo Basin, about 600 000 km² (Dittrick, 2013) is about three times larger than the Permian Basin (Texas, USA), which extends over 220 000 km² (Kelly *et al.*, 2012). The Permian Basin is currently one of the preferred shale areas in the USA with 550¹⁹ rigs currently employed. The prospective area in the Karoo is estimated to be between 60 000 km² and 200 000 km². For the initial development phase, a rig count of about 60 rigs is projected (Hsieh, 2014). In the case of a sustainable development phase over a 25-year period (the dti, 2014), it is assumed that this number could increase to 200 to 500 rigs, based on an average lateral well length of 2 000 m, 300 m well spacing, an average of 20 days for well construction and an accessibility or development ratio of 50% of the total area.

A standard well for the Karoo Basin, which is used for scenarios in subsequent sections, was defined as follows:

- The Whitehill Formation of the Lower Ecca Group is expected to be found in a depth range of 1 500 m to 5 000 m. Fracturing at 5 000 m depth poses challenges, however. Since a distribution of the depth range of the prospective area is not available at this stage, an average well depth of 2 500 m (Dittrick, 2013) was assumed.
- Lateral sections (horizontal drilling bores) in the Permian Basin are in the order of 1 370 m up to 1 770 m (Kelly *et al.*, 2012). In many places

¹⁹ Baker Hughes International Rig Count: <http://phx.corporate-ir.net/phoenix.zhtml?c=79687&p=irol-rig-countsintl>. Website last visited: 06.11.2014.

in the USA, longer laterals are drilled, and therefore an average lateral (horizontal bore) length of 2 000 m was selected as representative for the Karoo.

The casing programme, in an advanced stage of the development, was defined as follows:

- a 13 $\frac{3}{8}$ " (340 mm) surface casing to 400 m;
- a 9 $\frac{5}{8}$ " (244.5 mm) intermediate casing to 2 200 m;
- a 5 $\frac{1}{2}$ " (139.7 mm) production casing string to 4 700 m measured hole depth.

6.1.2 Amount and Quality of Water Required for Drilling a Well

Being distinct from hydraulic fracturing operations, drilling operations do not account significantly for the total water requirements of a well. An entire well life cycle should be considered. Furthermore, there needs to be a distinction between direct and indirect water use of a well, as shown in Figure 6-1.

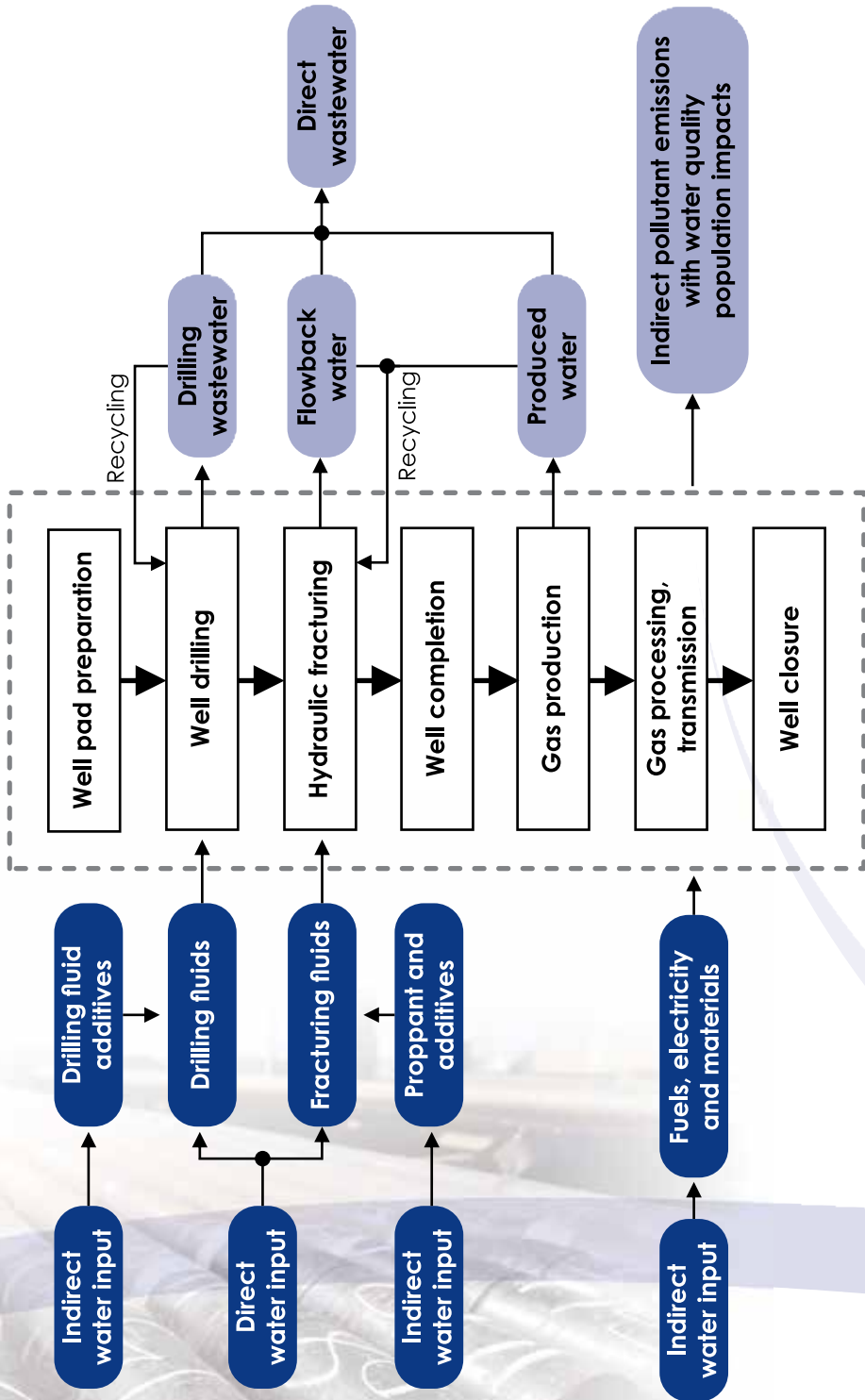


Figure 6-1: Direct and indirect water use for a shale gas/oil well (Jiang et al., 2013)

The amount of fluid required for the drilling operations depends on the well casing and bit programme or, in general, the volume of hole that is created. For the exploration and appraisal phase, more casing strings will be needed until geological factors are well understood. The type of mud to be used has to be especially designed for shale formations. For conventional rocks such as sandstone or carbonates, WBM are used. If longer shale sections containing large fractions of clay minerals have to be drilled, then oil-based muds (OBMs) or even synthetic-based muds (SBM) are used (Guo *et al.*, 2012). Little information is available for the Whitehill Formation. Quartz is predominant, with pyrite that was recorded in one sample (Naledi, 2015). This indicates that WBMs may be used in the Karoo.

OBMs have the disadvantages of environmental incompatibility and adverse economics and therefore the industry focuses on developing WBMs for shale plays. Because every shale is different, WBMs have to be optimised for each area, whenever the mineralogy changes and especially if the shale contains water sensitive components (Deville *et al.*, 2011).

The amount of water required for hydraulic fracturing operations is different for every well and varies significantly. The base fluid is water. Various additives are required to achieve proper fracturing fluid properties for the treatment. The quality of the water is important, as the drilling mud as well as the fracturing fluid have to fulfil certain standards in order to achieve the necessary properties. Depending on the source, the water may be contaminated with solids or may be too saline, or hydraulic fracturing flowback water may be used. In these cases the water has to be treated.

It is estimated that the amount of water required for drilling operations per well is about 330 m³ and it is assumed that the mud is reused for three wells. For hydraulic fracturing operations the range of water use is from 3 500 m³ up to 26 000 m³ per well, with an average of 15 000 m³ (Deville *et al.*, 2011). The flowback is in the range of 20% to 80% (Boschee, 2014; Smistad, 2013). This results in a range of about 3 800 m³ to 26 300 m³ for direct water consumption. Indirect water consumption can be an additional 4 100 m³ to 12 000 m³ per well (Smistad, 2013). If re-fracturing is considered in the well life cycle, the water consumption per well could be as high as 54 000 m³ (Smistad, 2013).

Water that is used to create drilling mud is usually sourced from surface water bodies, municipal treatment plants, industrial wastewater, ground-water aquifers, and deep or saline aquifers, etc. Flowback water from fracturing operations will also be reused. The water must be treated prior to hydraulic fracturing operations if withdrawn from a highly saline aquifer and flowback water must be treated to remove NORMs and solids prior to reuse, if the concentration exceeds thresholds. Any freshwater source should have a TDS concentration of less than 10 000 ppm (API, 2010). Untreated produced water with a TDS concentration of more than 20 000 ppm can be used as a base fluid for cross-linked gel (Huang *et al.*, 2005).

6.1.3 Specification for Casing and Inspection Criteria

The casing has to be designed for tension, collapse and burst forces for all operations during installation, cementing, hydraulic fracturing, and gas production. Furthermore, it has to withstand all conditions such as corrosive environments that can be reasonably anticipated during the life of the well. Minimum standards for casings are the American Petroleum Institute (API) 5CT and the International Organisation for Standardisation (ISO) 11960. As each shale gas well is hydraulically fractured, it is recommended that the internal pressure rating for new pipes, except the conductor casing, is at least 20% greater than the maximum pressures that the casing will be exposed to during hydraulic fracturing and the lifetime of the well. If the hydraulic fracturing process is carried out more than five years after its initial installation, the operator must provide evidence to the regulator that the casing is in a proper condition to maintain integrity during the stimulation treatment. Casing wear logs, cement evaluation logs, and corrosion and mechanical integrity tests may have to be provided for the assessment.

Casing joints that are used for well-control purposes are required to be threaded rather than welded. Welded casing bowls should at least meet all the relevant specifications set by, for example, API, American Society of Mechanical Engineers (ASME), etc. The make-up torque procedures for threaded casing and tubing connections, and all joint connection compounds should meet similar specifications.

6.1.4 Reliability of Hangers in Casings

The release of CH₄ into the environment during shale gas production is well documented (Howarth *et al.*, 2011). In the case of a primary subsurface barrier's failure (leaky tubing, packer, subsurface safety valves and/or cement), a secondary barrier like the seal of a tubing hanger or casing hanger should stop gas flow in the corresponding annulus at the well-head. Conventional casing hanger technology can incorporate assembly clearances or gaps which might be exacerbated when pressure is applied. These gaps cause movement ('fretting') between metal sealing parts when forces occur in the well-head as a result of pressure and temperature fluctuations throughout the field life of the well. The movement between metal sealing parts causes seal failure after a limited number of cycles. Conventional well-heads work from the 'inside out' and use a complex arrangement to set seals. In the case of a pressure build-up on the annulus, the well-heads are sometimes the weak link. Well-heads can, however, be designed to qualify as the strong link in the well chain, exceeding the integrity of premium couplings. This requires innovative solutions, of which 'outside in' technology is a good example.

It works from the 'outside in' (Subsea World News, 2015) by squeezing the well-head body onto the device that supports the pipe going into the ground using hydraulics. The designers believe that by using the 'outside in' technology in well-head systems, a number of significant advantages over existing 'slip and seal' and 'mandrel hanger' well-head technologies are offered.²⁰ 'Outside in' technology is successfully installed in many high-pressure offshore applications and according to the designers, it would be no problem to adapt the concept to shale gas well installations (Eisenhammer, 2013).

6.1.5 The Possibility of Using Production Casings to the Surface

Casings act as part of the barrier from the well-bore against the formations. Casings have to be designed for the predicted pressure, temperature and environmental conditions. Selecting the right steel quality allows the installation of the casing in various configurations. For shale gas wells, when hydraulic fracturing operations follow every drilling operation, casing strings must also be designed for the high treatment pressures.

The production casing can either be designed to extend over the entire well-bore length from the borehole bottom up to the surface; it can be installed as a liner from the bottom of the well up to a certain height above the previous intermediate casing string; or it could be designed as a liner with an extension back to the surface, which is called a tie back string. However, to be most effective, it is recommended that one long-string production casing (i.e. a casing extending over the full well depth) should be used (Natural Resources Defense Council, 2012).

Because of the high treatment pressures during hydraulic fracturing operations, special care must be taken regarding well integrity. It is important and it should be required by the regulator that both a 'primary barrier' and 'secondary barrier' for fracturing fluids are installed as a safety measure in the event that the 'primary barrier' mechanically fails. The 'primary barrier' could be either the production casing, the tie-back liner of the production casing, or the tubing.

The 'secondary barrier' is the intermediate casing. Despite the fact that it might not be possible to install an intermediate string, it is strongly recommended that an intermediate casing is always installed for safety and environmental reasons (New Brunswick Natural Gas Group, 2012).

6.1.6 Quality of Cement and Integrity

Much has been published on well integrity during the last decade, however much confusion exists about the definition of 'failures of barriers'

²⁰ <http://www.plexusplc.com/about/introduction-to-pos-grip>.

in well construction. One of the best clarifications recently given by King and King (2013) is as follows:

"There are significant differences between single-barrier failure in multiple barrier well design and outright well-integrity failure that could lead to pollution by use of published investigations and reviews from data sets of more than 600 000 wells worldwide. For USA wells, while individual-barrier failures (containment maintained and no pollution indicated) in a specific well group may range from very low to several percent (depending on geographical area, operator, era, well type, and maintenance quality), actual well-integrity failures are very rare. Well-integrity failure occurs when all barriers fail and a leak is possible. True well-integrity failure rates are two to three orders of magnitude lower than single-barrier-failure rates."

It is this study's conclusion that not all wells with a single barrier failure leak now or later; there can be multiple safety barriers and there must be a pressure or buoyancy gradient for fluids to migrate. However, to further decrease the relatively small risk of well-integrity failure, industry best practices for well construction must be a standard. In addition the integrity of shale wells must be monitored over the entire production period and beyond.

A large majority of wells that are subjected to barrier failures and sustained casing pressure do not create groundwater contamination problems. Even air pollution problems can be avoided when the well-head seals (e.g. casing hanger seal) and other secondary barrier elements are functional (See Section 6.1.4).

A typical well-bore is constructed by a series of concentric casing strings. These overlap, especially in the upper sections of the well. Thus, multiple layers of steel and cement usually isolate groundwater-bearing zones. There are several options for configurations described by Prohaska and Thonhauser (2012). Casing and cement will not only present a barrier for fluids that flow within the well-bore, they also act as a seal for fluids that may invade the annulus from outside. This function is generally known as zonal isolation, which is accomplished by a perfectly cemented annulus across, for example, the shale pay zone.

Badly cemented sections of the well-bore may occur, especially in highly deviated and horizontal sections. Reasons for this are bad casing centralisation or the impossibility of rotating long strings, among others. Therefore, it is important that the cementation of the casing shoe previous to the badly cemented section is fully functional. This barrier would effectively hinder fluid flow from lower to upper annuli.

The importance of a properly cemented casing shoe is illustrated in Figure 6-2. In this figure, the cement of the production section failed and back-flow or gas can enter the annulus between casing and formation. However, the cemented shoe of the prior intermediate casing stops further fluid flow. The only way fluids can continue to flow is across a leaking production liner hanger seal. Fluid and/or gas may then accumulate in the inside of the well-bore, between production liner and intermediate casing. Contamination of groundwater would not occur in this case as multiple barriers of steel tubes and cement are present in the upper parts of the well.

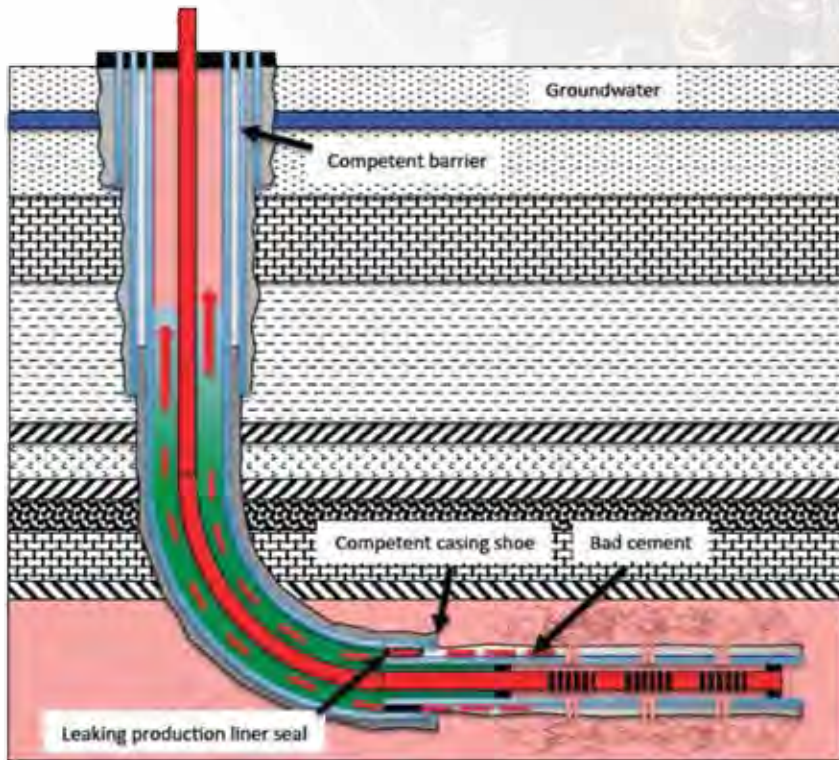


Figure 6-2: Scenario of unwanted fluid flow
(www.shale-gas-information-platform.org)

6.1.7 Cement Casings

The cement seals of the well-bore, or the casing strings, against the surrounding formations prevent unwanted formation fluids from flowing into the well and vice versa. Many challenges have to be overcome to provide a perfect sealing cement over the entire column: bonding problems, displacement problem, micro-annuli and many more issues might allow leakage through the cement. For many decades the issue of proper well-bore casing and cementing has been widely discussed by

industry and regulators. Major best practices for zonal isolation have been developed and are listed as follows:

- Casing qualities and connections must follow API Specification 5CT (as a minimum).
- Cement formulation and chemistry must be compatible with formation fluids, spacer/mud fluid chemistry and temperature.
- During cementing, the best available mud displacement method to avoid mud channels has to be chosen (Haut and Crook, 1979) (i.e. centralise casing, condition of bore-hole, reciprocate and rotate the casing and use spacers in turbulent flow).
- The use of both top and bottom cementing plugs is highly recommended (Baker Hughes, 2012). As the top plug is almost always used, the bottom plug is sometimes left out. However, this plug is important because it mechanically separates drilling mud from cement slurry inside the casing, minimising mixing of fluids during pumping.
- Provide a thin and low-permeability filter cake for the drilling fluid during the drilling phase and destroy thick filter cakes mechanically by scratchers during running of the casing (Griffith and Osisanya, 1995). This will reduce the risk for later micro-annuli between the cement and the rock formation.
- Reduce cement slurry filtration (Sutton and Sabins, 1991) (<50ml/30min API fluid loss value) to avoid 'bridging' during cement setting with the consequence of uncontrolled 'take over' of hydrostatic pressure in the upper parts of the well. This is of special importance when isolating formations with higher pressure or areas with punctuated pressurised biogenic gas pockets in the lower parts of the well.
- Reduce slurry chemical shrinkage to a minimum or even consider expanding cement systems to avoid micro-annuli between casing/cement and improve the bonding (Baumgarte *et al.*, 1999).
- Note that volumetric reductions of the slurry during the static transition time after cement pumping (time until the gel strength reaches 239 Pa) could be substituted by gas, allowing subsequent bubble migration and the formation of micro-channels. This could lead to a communication between formations and in the worst case to an underground blowout. As a solution, slurries with low shrinkage and low filtration values, and high gel strength after pressure balance are recommended so as to limit bubble migration (Prohaska *et al.*, 1995).

- The use of right-angle setting slurries (Santra *et al.*, 2007) will reduce the time gas can migrate within the unset cement. Such systems are applied across high-pressure gas zones; they can develop sufficient strength to hinder gas percolation (Sutton *et al.*, 1982) (e.g. 239 Pa) within a short period of time. Thus, gas migration will stop within an acceptable distance above the gas entry point.
- The use of lightweight cements will avoid cement losses in the case of weak (surface) formations (Kulkarni and Hina, 1999). Thus one would use lost circulation material if appropriate.
- The use of inflatable annular casing packers can significantly enhance a standard cement job by providing specific points of isolation. The positioning of an annular casing packer near a surface casing shoe would ensure a permanent pressure seal.²¹
- For surface casing applications cement should always be planned to extend to the surface, without exclusion. If cement does not appear at the surface during pumping, parasitic pipe and cement through the annulus should be used (Nelson, 1990).
- A cement bond log (CBL) should be run to determine the quality of a cement job and to plan a repair squeeze if required. However, CBLs can give a reasonable estimate of bonding and a semi-quantitative idea of the presence or absence of larger cement channels, but will not certify pressure or hydraulic isolation of a zone. Field performance for a properly run and calibrated CBL is approximately 90% in finding channels of 10% or more of total annular space.
- If the cement in a section of the well fails to pass testing requirements, the cement isolation must be repaired before drilling of the next section can commence.
- Note that a sufficiently large compressive strength of the cement needs to develop during a waiting time before performing a CBL test and continuing with drilling operations. Typically waiting times can be up to several days during which the rig is 'not productive' but still consumes the 'day rate'.
- Cement does not need to be perfect over every foot of the cemented area, but at least some part of the cement column must form a durable and permanent seal. The continuous bounded interval represents the length of continuous good quality cement behind a casing. It depends on casing diameter and should follow recommendations (Douglas *et*

²¹ *Inflatable Packers Catalog*, Weatherford, found in April 2012, www.weatherford.com/weatherford/groups/web/documents/weatherfordcorp/wft003553.pdf.

al., 2006) like the 10 m of continuous bounded interval for a 7" (177.8 mm) casing or 14 m for a 9 5/8" (244.5 mm) casing (recommended by EPA, US Environmental Protection Agency). Other studies generally suggest that the required amount of this 'perfect' cement in a longer column should be at least 15 m (King and King, 2013).

- Once a section has been drilled, cased and cemented, a pressure integrity test of the formation strength immediately below a casing shoe should be performed to ensure that there is an adequate seal at this location to prevent any fluid migration through the casing annulus (Morita *et al.*, 1997).

6.1.8 Pressure Testing of the Well

Oil and gas wells are exposed to high pressures during the entire well lifetime. In order to maintain well integrity, all the relevant parts of a well, such as casing strings, valves, cement, etc., have to be in a proper mechanical condition to fulfil those criteria. Clarification of the proper well condition can only be obtained by pressure testing the wells. Prior to drilling out the surface, intermediate or the production section, all the components of the well should be pressure tested. All casing and tubing strings that are exposed to hydraulic fracturing operations should be tested with water, mud or brine to a pressure of at least 3 500 kPa greater than the maximum anticipated pressure of the stimulation or the well life. If the pressure can be maintained for 30 minutes and does not drop more than 5%, the permit may be granted.

Similarly, prior to pumping a hydraulic fracturing stage, injection lines manifold, associated valves, fracture tree and any other well-head component or connection, which was not previously tested must be tested to the maximum anticipated treatment pressure and with the same pressure loss requirements and actions as stated in the paragraph above.

6.1.9 Well Closure

Temporary and permanent well closures should be differentiated, with the former implying that production will continue in future, and the latter implying permanent sealing of the well, with the well having no further utility. Proper well closure procedures accomplish the following (Department of Environmental Protection, Pennsylvania):

- Eliminates the physical hazard of the well (the hole in the ground).
- Eliminates a pathway for migration of contamination.
- Prevents hydrologic changes in the aquifer system, such as the changes in hydraulic head and the mixing of water between aquifers.

The proper decommissioning method will depend on both the reason for abandonment and the condition and construction details of the well. Well closure procedures involve setting of open-hole plugs or cement plugs (perforations, casing shoes, open-hole sections, etc. which is defined by the regulator), potential cutting of the surface casing 2 - 3 m below the surface, welding a steel plate on surface casing stub, filling of the well cellar and restoring the well site near to conditions that existed prior to drilling the well (API, 2009b).

Care has to be taken by defining the liability of the well for the period after the abandonment. This has to be defined by the regulator.

6.1.10 Availability of Drilling Rigs in South Africa

According to the historical rig count (Baker Hughes International Rig Count)²², it is clear that South Africa lacks a rig market that could support the development of the shale gas industry in the near future. Onshore rig activity particularly has been absent for 20 years.

For a near-future exploration phase, the only current option to have rigs available in South Africa is via agents. The most suitable products currently available are for shallow oil and gas exploration, which allow a maximum hook load of 226 tons.²³ It is estimated that the number of high powered (2 000 hp) drilling rigs in South Africa will increase from zero up to 60 by 2016 (Hsieh, 2014). However, given the timing of this report, this estimate will likely not be met.

Comparing the size of the Karoo Basin, about 600 000 km² (Hsieh, 2014) with the Permian Basin in the USA, which extends over an area of 86 000 km² (Kelly *et al.*, 2012) and where approximately 1 000 rigs currently operate²⁴, it is clear that South Africa lacks the necessary market for large-scale development. A scenario, as discussed in Section 6.1.1, shows that 200 to 500 rigs are predicted to operate in the Karoo if the commercially exploitable size of the Karoo turns out to be between 60 000 and 200 000 km² and is highly accessible. It follows that South Africa needs to develop such a rig market within the country and put in place the necessary regulations to foster market development or bring a large number of rigs into the country from outside.

²² Baker Hughes International Rig Count: <http://phx.corporate-ir.net/phoenix.zhtml?c=79687&p=irol-rigcountsintl>. Website last visited: 6 November 2014.

²³ Astec Industries Company. <http://www.osborn.co.za/?q=content/gefco-drill-rigs>. Website last visited: 06 November 2014.

²⁴ Baker Hughes International Rig Count: <http://phx.corporate-ir.net/phoenix.zhtml?c=79687&p=irol-rigcountsintl>. Website last visited: 6 November 2014.

6.1.11 Availability of Cement in South Africa

One of the leading suppliers of oil well cements (Imerys Oilfield Solutions²⁵) has mines all around the world and also in South Africa and one of the ingredients, bentonite, is mined in South Africa.²⁶ The volume of cement produced annually by the Pretoria Cement Company is reported to be more than 7 million tons per year.²⁷ (The entire market capacity obviously is much larger, however exact volumes could not be sourced.) The required cement volume for a standard well as defined in Section 6.1.1 is shown in Table 6-1. It is assumed that all casing strings, except the production casing, are cemented back to surface. The overlap of the cement between the production and intermediate section is 60 m (Natural Resources Defense Council, 2012). An annular open-hole excess volume of 20% is considered in addition.

Table 6-1: Future cement demand

	Dimension	Scenario			
Casing Length (Conductor, Surface, Intermediate, Production)	(m)	30	400	2 200	4 700
Casing Diameter (Conductor, Surface, Intermediate, Production)	(in)	20	13 ³ / ₈	9 ⁵ / ₈	5 ¹ / ₂
		508	340	244.5	139.7
Cement Slurry Volume	(m ³)	2	33	80	75
Cement Mass per Well	(t)	226			
Mass for 600 Wells per Year	(t/a)	135 000			

Table 6-1 shows that even for a full-scale development, only 2% of the Pretoria Cement Company's cement production would be required to supply all the wells with enough cement. As there are many more producers in South Africa, it is not anticipated that the supply of cement would be a major issue. The issue, however, is the cement quality. South Africa only makes Portland cements under the South African Bureau of Standards specification SANS 50197 (based on the Euro specification (EN) 197). These are general building and construction cements. Deep oil wells require special cements that are not covered by SANS 50197. These special cements are also essentially Portland cements, but with significantly different properties (e.g. more coarsely ground, significantly lower early strength, fairly low aluminate contents depending on the aggressiveness of the groundwater, and carefully controlled sulphate contents to control

²⁵ Imerys Oilfield Solutions: <http://www.imerys-oilfieldsolutions.com/Bentonite.html>. Website last visited: 10 November 2014.

²⁶ Ibid.

²⁷ Wikipedia, http://en.wikipedia.org/wiki/Pretoria_Portland_Cement_Company, Webpage last visited: 14 November 2014.

early setting). Thus, production processes of domestic cement producers would have to be adjusted to make the required Portland cement available within the country. Cementing services of the major oilfield service providers are not available directly in South Africa. However, it is anticipated that the experience in the USA would allow those companies to transfer the experience and equipment into South Africa if necessary.

6.1.12 Availability of Casing in South Africa

There is only one producer, namely Arcelor Mittal, which meets API, ISO and the Euro specification (EN) standards for tubular products and casing manufacture for the oil and gas industry in South Africa. The plant is located in Vereeniging and produces 100 000 tons of final tubular products each year. According to the company website, 80% of that is exported.²⁸

It is very likely that if the market develops, it will be commercially viable for producers to manufacture the required steel pipes within South Africa, as not only casings will be required but many more steel pipes, such as pipelines. However, for increased quantities of steel pipes with the required qualities, either domestic producers will have to increase their production capacity or pipes will have to be imported from the international market.

In the USA, 4½" to 7" (114.3 mm 177.8 mm) casings are installed in the production section of wells (Guo *et al.*, 2012). If the entire casing production of Arcelor Mittal, *viz.* 100 000 tons per annum, were to be allocated to manufacture production casing strings, there would still not be enough. The current production for the entire string of 600 wells per annum would satisfy slightly more than 50% of the demand.

Regarding casings, it can be concluded that for a development of scale, heavy investments in pipe building capacity would have to be established if these are to be locally sourced.

6.1.13 Summary

The following conclusions can be drawn regarding challenges and options for South African shale gas drilling operations.

Shale gas development is a manufacturing process unlike conventional oil and gas developments on and offshore. Consequently, it is necessary to build a robust field development model to understand and plan all relevant aspects of establishing the technical capacity to develop the field, including environmental and socio-economic impacts. It is also necessary to perform pilot field development work as part of the exploration phase to establish a local technical baseline as input to

²⁸ Arcelor Mittal South Africa: <http://www.arcelormittalsa.com/Operations/TubularProducts.aspx>. Webpage last visited: 6 November 2014.

the model (water usage, resource requirements, emissions). Without this information, strategic decisions and negotiations of production licensing agreements with potential operators will not be efficient.

General problems related to shale gas drilling include the following:

- For shale drilling, a large number of the production sections are drilled with OBMs. Using WBMs for the entire well requires specific developments and research of such muds for every type of shale. If South Africa opts for an environmentally friendly development, effort has to put into the mineralogical evaluation of the shale formation to develop specific WBMs.
- Direct water requirements for shale gas/oil well operations are estimated to be 3 800 m³ to 26 300 m³ per well. Indirect water consumption can require an additional 4 000 m³ to 12 000 m³ of water per well. As the Karoo Basin is an arid area, water is difficult to source. Given that it is most unlikely that it will be acceptable to use groundwater from shallow aquifers, the main source of water will be from deep saline aquifers. Operators will have to present detailed water management plans e.g. source of water, chemicals injected, reuse and recycling plans and wastewater management.
- Due to the quality requirements, many constituents such as TDS and other constituents such as NORMs would have to be reduced to certain limits.
- Casings are standard products in the oil industry and various standards exist. Minimum specifications are those of the API and ISO. Those standards should be evaluated for local circumstances and may lead to additional requirements being imposed by the regulator.
- CH₄ spills into the environment during shale gas production do occur and can be related to well-head secondary barrier failures and/or leakages in pipelines and gas separation/processing facilities. From the well construction point of view, some innovative well-head solutions exist which could be adopted for shale gas wells on a large scale in the near future.
- Installing the production casing string up to the surface is a standard application in the oil and gas industry. An important consideration is that the regulator should require two barriers for the fluids, be it production casing and intermediate casing, tie-back liner and intermediate casing or another configuration.
- Contamination of groundwater by liquids related to well-bore integrity failures is extremely unlikely. More likely is the contamination with gas if

primary barriers fail. Cementing best practices have been developed to minimise these risks. As a consequence, however, strict regulations are required to evaluate the quality of cement jobs, the integrity of the cemented casing shoe and the existence of a minimum continuous bounded interval.

- Pressure test operations are of paramount importance for oil and gas wells, especially shale gas wells which pose a special risk because of the additional high-pressure hydraulic fracturing treatments. Operators should follow special regulations to ensure well integrity under high pressure over the entire life cycle of the well.
- The legislation for well closure must be defined carefully to ensure a proper sealing of the well after the production period. The regulator has to define the liability of potential issues after well closure.

Special challenges related to shale gas drilling in South Africa include issues relating to the provision of an adequate number of rigs, availability of casings and the correct quality of cement, and the development of the necessary skills base within the country. Ensuring well-integrity must remain the highest priority to prevent short term air pollution, and long term (>50 years) contamination of the critical zone (ecosystems, soil, water). There must be lifelong instrumentation (processes) in place to monitor 'closed wells' and there is a need for clarity on severance or well-retirement tax, irrespective of a reported/immediate damage.

6.2 Distribution and Exploitation of Shale Gas

6.2.1 Introduction

The International Energy Agency (IEA) has heralded "a golden age of gas" moving forward to 2035 and beyond, predicated on the recent North American shale gas boom, expansion of conventional gas discoveries, and growing global concerns about energy security and climate change (IEA, 2011).

The principal global market opportunity for natural gas is in power generation, accounting for more than 40% of its total consumption (IEA, 2014). Gas-to-power plants are modular and relatively cheap compared to other base-load options, can be deployed quickly within a favourable regulatory environment, and are roughly 40 - 50% less carbon intensive than coal.²⁹ In addition, gas power plants have a much faster dynamic response, and are the only active generating technology capable of

²⁹ This is based entirely on combustion efficiency differences for steam generation. System-wide differences require a life cycle analysis. Given that gas fired power plants are likely to be deployed in coastal regions, the net benefits of gas over coal could be much greater, as all power transmissions losses from Mpumalanga coal-fired plant are mitigated.

accommodating the intermittency of renewables, in order to ensure grid stability in the absence of utility scale storage options.

At the same time, South Africa's current use of natural gas is small in terms of its energy footprint and relatively recent, based largely on importation of compressed natural gas (CNG) from Mozambique since 2005 for Sasol and other Gauteng/KwaZulu-Natal users, and offshore gas for PetroSA's Moss gas refinery. Expanded offshore exploration for natural gas off the Southern and Western Cape coast, has been under way for some time, but only small deposits have been identified to date and none has been commercialised.

Apart from PetroSA's offshore pipeline to the Moss gas refinery, South Africa's natural gas transmission and distribution infrastructure is concentrated in Gauteng and Mpumalanga. The Republic of Mozambique Pipeline Investment Company (ROMPCO) pipeline feeds imported natural gas from Mozambique's Pande and Temane gas fields principally to Sasol's Secunda operations, but also supports industrial, commercial and (a small number of) residential customers through several gas trading and distribution companies (e.g. Egoli Gas, Novo Energy, and Spring Lights). The 865 km pipeline to Secunda has a carrying capacity of 183 MM GJ/annum. Sasol is the majority shareholder at 50%, with the Mozambique government and iGas, a South African state-owned enterprise, each owning 25%. In 2014, Sasol Gas sold 170.8 million GJ to its customers. Looking forward, such a gas transmission/distribution model could be replicated in other parts of the country to serve different markets supplied by Karoo shale gas.

Even conservative estimates of the Karoo shale gas reserve have led to impressive (and perhaps exaggerated) predictions, related to the potential economic benefits which could be derived from its exploitation. Econometrix (2012) estimated that a reserve of 20 tcf could deliver a contribution to gross domestic product (GDP) in excess of R2 trillion, close to R1 billion in government revenues, and in excess of 350 000 jobs. Such estimates are based on conventional economic modelling, in which the economy is divided into a number of productive sectors via a Social Accounting Matrix, from which the impact of gas availability is cascaded through to GDP and employment numbers via the use of simple economic multipliers. The Econometrix model was moderated by reference to studies of the developed Marcellus deposit in the USA (Kinnaman, 2011) and the potential Lancashire deposit in the UK (Regeneris Consulting, 2011).

It is recognised that South Africa is in a substantially different position from the USA and UK, both of which have extensive, well-established gas distribution networks to service diverse market opportunities. There are also concerns about the real employment generation potential of Karoo shale gas production (e.g. Wait and Rossouw, 2014). In this light, the use of

generalised economic modelling analyses should be treated with some circumspection. McKinsey & Co. (2015) has estimated that even 1/10th of the USA EIA reserve estimate could deliver significant industry development under certain plausible assumptions. Such calculations are predicated on a host of assumptions, which, at this stage of resource development, cannot be substantiated.

More pointedly, it is important to distinguish between the general opportunity that can flow from natural gas, and that which is particular to the development of Karoo shale gas. The South African Oil and Gas Alliance (SAOGA, 2014) declared that local gas exploration needs to confirm a minimum reserve of 10 tcf to be competitive with imports, and in order to 'complete' the gas value chain and maximise market off-take prospects.

Price Waterhouse Coopers (PWC, 2012) highlighted the real conundrum facing gas market development in South Africa:

"In order to develop, large anchor customers using significant gas volumes are required. Indigenous reserves must still be proven and this can only be achieved with significant capital outlay. Exploration and production (E&P) companies are, however, unwilling to commit to this without demand commitments, and the potential anchor customers that could create this demand are unwilling to commit until reserves are proven."

These (and similar) perspectives give rise to three observations:

- 1 The well-head price of Karoo shale gas will dictate the level of all economic development-based on this resource.³⁰
- 2 The macro-economic model which informs this analysis is one in which South Africa's pivotal role in emerging economies is not only sustained, but grows in importance, giving South Africa more influence to negotiate trade deals, and to serve as an economic bridgehead into Africa, etc.

³⁰ It is impossible to predict what this number will be without extensive exploration, which will necessitate hydraulic fracturing. As pointed out by WWF (2015), the market price of shale gas is complicated further by issues such as royalty rates, government "free carry" quotas, and tax waivers. Many of these uncertainties are bound up in the proposed 2014 amendment to the MPRDA which met with considerable industry resistance due to these uncertainties. As of mid-January 2015, the MPRDA bill amendment has been returned to Parliament, and the Minister of Mineral Resources is considering a different model in which energy minerals will be treated separately to metallic minerals. If this position succeeds, it could see a closer alignment between the Departments of Energy, Mineral Resources, and Public Enterprises, which will have immediate bearing on how the Karoo shale gas opportunity is managed. In the interregnum, investment uncertainty remains.

- 3 The structure of the South African economy going forward is largely invariant, i.e. it will remain an energy-intensive economy predicated on primary resources.

Any estimation of market opportunity (particularly those predicated on export earnings) needs to consider the selling price of globally-traded commodities, and back-calculate to the maximum well-head price in order to ensure that a financially viable project opportunity can be realised. This is the formative logic of the McKinsey & Co. study for the dti (McKinsey & Co., 2015). South Africa has very little opportunity to influence the price of globally traded commodities based on natural gas (e.g. LNG, methanol, urea and ammonia), and is essentially a price taker. This fact will impact the business case for any ambitious Karoo shale gas market development.

6.2.2 Gas-to-Electricity

South Africa has faced severe electricity supply constraints since 2007 - 2008. As of January 2015, it is predicted that these will persist for the next five to ten years, despite significant current investment in new infrastructure, including both coal and utility-scale renewable power generation projects. How the situation will be resolved, and what role natural gas will play in its resolution, will impact directly on gas market development, including any subsequent use of Karoo shale gas, should this resource prove to be economically recoverable in an environmentally responsible manner.

Gas power plants are modular, relatively cheap, and much faster to build than other base-load options, such as coal and nuclear. Their modularity allows for a wide range of installed capacities, anywhere from 1 - 6 000 MWe. On the smaller end of the scale, they are often dedicated to single customers such as energy-intensive industries. Construction lead times are typically two to three years, assuming all regulatory approvals are in place.

Gas-fired power plants are dominated by two different technologies: either reciprocating gas engines or gas turbines. To achieve the highest operating efficiencies (55% - 60%), they need to operate in combined cycle mode, where exhaust heat from the engine/turbine is fed to a steam generator which drives a steam turbine. The relative merits of gas engines and turbines are a function of plant size, operating mode, and site energy and water management requirements. In combined cycle mode, both options emit roughly 50% less CO₂ than coal plants per unit of delivered power, and as such have a large role to play in a carbon-constrained economy. Of particular importance for South Africa is that gas-fired power generation can enable a distributed electricity grid infrastructure, supporting both coastal energy demand, and utility scale renewables. At the same time, the availability of natural gas in the north-east of the

country (via the existing ROMPCO pipeline or otherwise) can greatly assist Eskom to decommission its ageing power plants in that region, without sacrificing existing investment in electricity transmission infrastructure.

South Africa's currently installed gas turbine capacity is small, and is dominated by Eskom's two turnkey³¹ diesel-fired open cycle peaking power plants in the west, built over the period 2005 - 2009. Both operate at about 27% efficiency. The business case to convert both plants to combined cycle operation is straightforward, and predicated on affordable natural gas.

The above-stated advantages of 'gas-to-power' have not percolated through South Africa's national energy planning to date, primarily because of the perception that a gas-driven economy cannot proceed without indigenous gas resources. The government approved the Integrated Resource Plan (IRP) 2010 for electricity (Department of Energy, DoE, 2010), which maps out investment in new generating capacity to 2030, allowed for only small amounts of gas-fired power.³² The 2013 update (DoE, 2013a) takes a more positive stance regarding gas-to-power, and there are several scenarios in which gas power plants make a significant contribution to the country's energy mix.³³ Contrasting the extremes of these two policy documents, South Africa could commit to anywhere between 6 000 MWe and 70 000 MWe of gas-fired power generation by 2050, depending on the underlying modelling assumptions. This vast difference is attributed largely to the inclusion of Karoo shale gas in the IRP update 'big gas' scenario. What is important to recognise is that, regardless of the size of the shale gas reserve, gas-fired power plants will likely be constructed close to regions of high electricity demand, and in a way which supports distributed power generation. Both suggest that this will serve coastal markets in preference to the Karoo itself.

Key points to consider in this context are:

- 1 Eskom acknowledges that gas-to-power offers the only base load opportunity to handle diurnal peaks and dispatch intermittency of renewables. Coal and nuclear are incapable of doing so. Gas turbines can synchronise to the grid in a matter of minutes. Any development scenario in which renewable energy power generation is encouraged needs to build on this reality.

³¹ All gas turbine technology is currently imported. The localisation opportunity is primarily in engineering services, construction, operation and maintenance.

³² The Policy Adjusted version of the IRP 2010 development plan allowed for new investment of 2 370 MWe of CCGT and 3 910 MWe open cycle gas turbine (OCGT) by 2030.

³³ The so-called 'Big Gas' scenario (predicated on Karoo shale gas plus regional imports from countries such as Mozambique) sees new gas power investments of 62 480 MWe CCGT plus 6 720 MWe OCGT to 2050. In this same scenario there is no new nuclear capacity built.

- 2 The DoE's IRP for electricity is a continuing work in progress. The current version of the plan approved by Cabinet (IRP, 2010) was based on modelling work done at a time that preceded the global financial crisis, resulting in an over-estimate of demand, and under-estimates of the learning rates associated with utility scale renewables, and nuclear capital costs.
- 3 The nexus of gas and renewables will impact on existing municipal revenue models, which, in turn, will impact on service delivery and local economic development. Any consideration of shale gas potential needs to engage with this agenda.
- 4 Reticulation of shale gas to coastal markets will provide a differentially positive benefit to those economic hubs, by providing energy security, pricing predictability, and lower carbon electricity than is currently provided by the national grid.
- 5 Gas-to-power technologies can be deployed in a modular fashion, matching demand and supply more easily than chunky energy investments into coal and nuclear.

6.2.3 Gas for Industry

The process energy needs of South African industry are served in the main by coal, heavy fuel oil (HFO) and liquefied petroleum gas (LPG), and recently by CNG imported from Mozambique. According to the Draft 2012 Integrated Energy Planning Report (IEP) (DoE, 2013b), process heating requirements dominate. Other process uses include the use of carbonaceous fuels for chemical reduction (e.g. in iron and steel). The same draft IEP examines the projected growth in coal and gas demand for the major industry sectors. Comparing these two trends leads to the observation that there is little anticipated growth in iron and steel, and no apparent opportunity for natural gas in this industry. The main use of natural gas will be in 'other manufacturing', i.e. outside of mining, metals and chemicals. This implies a shift to smaller, more distributed business opportunities, e.g. food and beverage.

It is clear from direct industry engagement³⁴ that the trend assertions in the draft IEP are questionable. Industries such as cement, iron-and-steel, base metals and platinum-group metals, and others have all expressed keen interest in using natural gas to improve their competitiveness. Much of this is based on the ease of installation, cleanliness, and response time of natural gas for heating; but is ultimately a function of gas price. It is

³⁴ The study by McKinsey & Co., "Gas-based industrialisation strategy" project for the dti brought together representatives from all major energy industries in the country. A series of workshops over November and December 2014 confirmed the strong interest in natural gas for direct industry use.

not the place of this report to conduct a full market analysis for each of these industry sectors. Each faces different challenges in terms of global competitiveness, but share a common problem in their high energy operating costs. Key points to consider include:

- 1 The marginal cost of energy provision to different industries varies widely, as does the attendant benefit. South Africa needs to adopt an energy pricing regulatory environment which recognises this.
- 2 Opportunities for fuel switching to natural gas are a function of industry location. By way of example, the price of coal for industry in the Western Cape can be two to three times the price in Gauteng/Mpumalanga.
- 3 It is important to distinguish between brown-field and green-field opportunities and their relative investment risk. Increasingly, there is a major role for public-private partnerships.
- 4 In many cases, local industry competitiveness cannot be divorced from global market dynamics and South Africa is generally a 'price taker'.
- 5 Natural gas can contribute to a substantive re-assessment of how energy efficiency improvements are assessed by industry. Here, the role of integrated energy management is critical as is the development of effective skills programmes.
- 6 There is no quantitative assessment available which examines the extent to which the uptake of natural gas by South African industry can assist the country to meet its international commitments to climate change mitigation. Equally, there has been no analysis of the extent to which the broad availability of natural gas for South African industry can drive regional industrial competitiveness.

6.2.4 Gas as Chemical Feedstock

Fossil energy feedstocks remain the key elements of the global chemicals industry. South Africa has a long history in this area, much of which is based on coal conversion, including the production of explosives, fertilisers, and synthetic fuels. Very little of this immediate coal value chain remains and South African companies have moved increasingly to the supply of niche products, accompanied by a strong sales focus and market support infrastructure.

The specific case of 'gas-to-liquid fuels' is covered separately within Section 6.2.5.

In this section, the focus is on the range of other chemicals which can be made from natural gas. These include, *inter alia*, hydrogen, ammonia and its derivatives (nitrogenous fertilisers, explosives, etc.), and an extremely wide range of plastics, solvents, surfactants, surface coatings and more. The economic viability of using natural gas (including shale gas) as a chemical feedstock is dependent on the cost of shale gas, the size of the market and its willingness to pay, and global pricing structures. At the same time, there is potential to grow market share in Africa as a whole, depending on the pace at which South Africa can develop its indigenous gas resources relative to other African countries.

South African production will need to be competitive with global imports, with the exception of certain niche products such as selected mining chemicals, where South Africa enjoys a unique advantage due to the maturity of that industry. Whilst the absolute number of artisans, technicians, scientists, engineers, etc. will need to grow to support a bigger chemicals industry, the education and training foundations are already in place to support a strong chemicals from gas industry.

Economic development challenges in the region suggest that there may be new market opportunities for locally produced chemicals. New building materials, improved health care products, innovative water treatment and energy storage solutions, are all examples of downstream market opportunities for natural-gas based chemicals. Export markets for locally produced chemicals will increasingly demand objective analysis of product carbon and water footprints. This clearly goes beyond the shale gas opportunity, but it is important to take this into account.

6.2.5 Gas for Transport Fuels

Before outlining the potential role of natural gas in the transport sector, it is important to summarise the *status quo*.

South Africa refines imported crude oil to meet the bulk of its liquid fuel requirements. The country is served by four oil refineries (three coastal and one inland,) with a total crude throughput of roughly 500 000³⁵ barrels/day (bbl/day). Sasol adds a further 150 000 bbl/day, and PetroSA 45 000³⁶ bbl/day (equivalents), through their respective synthetic fuel operations.

The national liquid fuels master plan acknowledges the country's vulnerability in terms of security of supply, foreign exchange risk, ageing

³⁵ Oil refining benefits from huge economies of scale. A single new generation refinery can process more than the total South Africa throughput. One immediate implication of this is that it is cheaper to land refine a product in South Africa than it is to import and process crude oil. Without cheap local primary energy resources, this situation will persist.

³⁶ In 2014, PetroSA's MOSSGAS refinery was operating at roughly $\frac{1}{3}$ of design capacity due to a shortage of gas supply.

refinery infrastructure and capacity constraints³⁷, and competitive pressures to improve fuel quality standards.³⁸ At the same time, the liquid fuel pricing regulations and subsidies have introduced a number of anomalies between the way in which different fuel products are handled, and how different markets are supported (DoE, 2013c).

Internationally, natural gas (in the form of CNG), as well as LPG, have both been used as alternative transport fuels to petrol in spark-ignition engines for a considerable time. Recent advances in engine design allow for dual fuel usage in compression ignition engines, thereby providing an opportunity for gas as a diesel substitute. There is also growing global interest in the use of LNG for heavy duty freight transport (trucks, trains and ships). Southern African experience in this area commenced in 2013 in Mozambique, with fuel depots supplying CNG to buses and taxis. In 2014, Gauteng province began a programme to encourage conversion of its minibus taxi fleet to CNG, and the City of Johannesburg is considering dual-fuel buses (with the ultimate aim of including bio-gas).

The case for direct fuel switching to gas is predicated on the following (adapted from Lloyd, 2014):

- Availability of fuel alternatives, including their delivery infrastructure.
- Engine suitability.
- Cost of vehicle adaptation or of bringing new engine designs to market.
- Net benefits (engine performance, CO₂ and other emission profiles, etc.).
- Localisation opportunities for manufacture.
- Consumer acceptance.

The environmental argument in favour of shale gas as a direct transport fuel is a complex one. There are no South African data in this area, and hence it is impossible to motivate for shale gas this way. The use of conventional natural gas as a transport fuel is easier to motivate from an environmental perspective. Natural gas can be converted to a range of liquid fuels, making the integration with existing engine technologies and fuel distribution infrastructures much easier. South Africa led the way internationally with Sasol's Secunda GTL plants, using gas from southern Mozambique and PetroSA's Mossel Bay refinery, which uses coastal gas from the Southern Cape fields.

³⁷ A new refinery of design capacity somewhere between 200 000 bbl/day and 400 000 bbl/day is mooted for development at the port of Nguru in the Eastern Cape. The business case for this is unclear, and as such, the proposition has met with considerable resistance.

³⁸ There remains considerable uncertainty as to how this capital improvement programme will be funded, and its costs recovered. It is also unclear the extent to which biofuel blending will impact this requirement.

The economic viability of GTL plants is strongly correlated with crude oil pricing. GTL requires a crude oil price in the region of \$100/bbl to be competitive, coupled to a shale gas well-head price of \$5/MMBtu (Shaw, 2012). Both of these assumptions are highly questionable, given global volatility in oil pricing, and the complete unknown of South African shale gas.

There are several alternative liquid fuels which can be made from natural gas, including methanol (European Parliamentary Research Service, 2014; Methanex, 2014); and di-methyl ether, a methanol derivative (Methanex, 2014). Innovation in catalyst development points the way to direct conversion of methane to methanol, thereby avoiding the costly reforming step to first produce synthesis gas. The commercial viability of any future methanol production from indigenous natural gas in South Africa will be linked to global commodity pricing for methanol (whose global production is dominated by China).

Looking to the future, decisions around South Africa's transport options will require clear policy signals based on holistic life cycle considerations, and supported by integrated energy planning. Given that transport contributes roughly 50% to the country's energy footprint (and environmental burden), this should become a strategic priority.

6.2.6 Gas for Domestic Applications

Whilst electricity is the (currently) preferred domestic energy source in urban South Africa, the three major household energy applications - cooking, space heating/cooling, and water heating - can, in principle, all be served by gas. This is a sizable market opportunity, but one, to date, which has had limited uptake in South Africa.

LPG is used more widely as a convenience fuel by niche-market domestic customers at the upper end of the socio-economic spectrum, and by restaurants and food retail outlets. The bulk of domestic/commercial LPG sales are by tanks/cylinders, distributed by road. Using natural gas for cooking and water heating is far more efficient than using fossil-based electricity when examined from a life cycle perspective, bringing immediate reduction in household carbon footprint. There is growing interest in the supply of LPG to low-income households, using smaller volume cylinders and 'corner-shop' retail distributors.

It is an important question going forward as to the relative roles of LPG and natural gas in the South African market place. This is an area requiring clear policy signals and effective regulation to support overall gas market development. The key challenge is to develop the requisite distribution infrastructure and operating systems. Recent Gauteng experience suggests that it is possible to establish a low-pressure CNG distribution system

quickly, provided there is sufficient market density, adequate available gas volume, and secure supplies.

The creation of new gas pipeline distribution infrastructure is straightforward. This is low-pressure piping, which can be co-located with other trenched services, including water, sewage and telecommunications. The big opportunity is to factor gas reticulation into the planning for new housing developments from the outset. The Mozambique experience, plus South Africa's mature gas fleet transport industry, suggest it is also possible to service established residential areas via a virtual network of depots.

Gas distribution would also provide a new revenue stream for local municipalities, which carry an energy distribution mandate under South Africa's constitution. The development of a robust domestic gas market will depend on the selling price of gas relative to electricity. As of 2015, both of these are regulated by the National Energy Regulator of South Africa (NERSA). Going forward, it will be important to understand the role of local municipalities in this space.

6.2.7 Local Economic Development

This section has made a case for shale gas development to be underpinned by the gas-to-power imperative; and that other market opportunities will be driven by market size and density. This realisation will likely translate into a situation in which the Karoo itself is a minor beneficiary of any potential shale gas bounty. Exceptions could include the distribution of CNG to local small-scale businesses, gas for transport, and gas for domestic applications. Given the relative size of such markets, gas distribution will most likely occur via virtual networks of tankers and bowsers.

6.2.8 Enabling Infrastructure

The bulk of this report has focused on the overall challenge of exploration and production of shale gas from the Karoo. As such, consideration of any enabling infrastructure has been limited to the production site. In this section, we discuss downstream market opportunities: their size, economic value, and challenges to their realisation, key to which is in establishing the necessary gas transmission and distribution infrastructure to points of market off-take, whether these be inland or coastal.

The cost of piped infrastructure is well known. Other cost data from the ROMPCO pipeline and the Gauteng gas distribution network are also known. In 2014, some indicative costs became available for a possible 2 500 km pipeline from northern Mozambique to South Africa (Eskom, 2014). Specific issues of concern relate to pipe routes and servitudes, environmental and other regulatory approvals, and compatibility with local and provincial spatial development planning. From a commercial

standpoint, there are a number of contractual risks associated with infrastructure projects of this nature. They are likely to be multi-party ventures, possibly public-private partnerships, with complex funding and financing arrangements. NERSA will play a major role in determining gas pricing and gas tariffs, as well as issuing licences for gas transmission and distribution, power generation, etc.

Collectively, all of the above issues suggest the need for South Africa to put in place a streamlined regulatory process which will enable gas infrastructure development projects to proceed without unnecessary delays. This will require a coordinated government approach.

6.2.9 Summary

Based on this analysis, the following conclusions can be drawn:

- 1 The South African gas market is potentially large. Whilst the shale gas opportunity is being assessed (five to ten years), there is an opportunity now to develop anchor markets based on CNG and LNG imports. Gas-to-power projects are essential for this development. There is strong commercial appetite for investing in the requisite infrastructure. The limiting constraint is national energy policy and regulation.
- 2 It is of utmost importance that the necessary policies are adopted to encourage usage of gas as an energy source and promote the development of a shale gas industry. This must be coupled with the implementation of the vision set out in the GUMP.
- 3 Market development is entirely predicated on the price of gas at point of use. Aspirations to develop export-oriented products, specifically, need to be checked in detail against the likely well-head cost of shale gas, transmission and conversion costs.
- 4 South Africa should prioritise research which demonstrates the overall environmental costs and benefits of the shale gas value chain.

6.3 Capacity and Skills Development

6.3.1 Introduction

As part of understanding the technical readiness of South Africa to develop shale gas, this section considers the scarce skills challenge associated with developing the shale gas industry in South Africa. It covers:

- 1 The skills needed to develop the shale gas industry in South Africa, taking into account current interventions that are addressing the issue of scarce skills.

- 2 The *status quo* in South Africa with regard to the requisite skills at all levels required for shale gas development.
- 3 Matters of concern relating to skills development in the short/medium and long term.

6.3.2 Skills Required for Developing the Shale Gas Industry in South Africa

The oil and gas industry is usually discussed in terms of its different sectors i.e. the upstream, midstream and downstream sectors. The upstream sector refers to the identification of the resource and then its extraction, viz. the exploration and production sector.

The midstream sector refers to the transportation of crude oil or gas away from the well-head for further processing. The processing facility (in the case of crude oil this is the refinery) is sometimes included in the midstream sector but it can also be included in the downstream sector. Typically, the downstream sector is the market facing sector, where the products are placed in the marketplace for consumption.

Whilst South Africa possesses an abundance of mineral resources, the one resource that until now has been absent is a meaningful oil/gas resource and hence the upstream sector is not well developed in the country.

As a result, it is in this sector that the major skills shortages will be experienced. In the mid and downstream sectors there is a shortage of some locally produced skills but not to the same extent as the shortage in the upstream sector. There are four crude refineries, the coal-to-liquid (CTL) plant in Secunda and the GTL plant at Mossel Bay that are in operation, and the logistics and marketing sectors for liquid fuels are well established.

In the upstream sector, the skills required include professionals or graduates to fill positions such as well engineer, production geologist, exploration geoscientist, reservoir engineer, geophysicist, petrophysicist, production technologist and management (Lindberg, 2014; Shell, 2014). Others that have been identified are referred to as 'transferable skills' and 'available skills' (Shell, 2014). 'Transferable skills' are typically production and maintenance operators, project and discipline engineers, process engineers, health/safety/environment practitioners, qualified artisans from all trades.

'Available skills' are those in the areas of human resources, information technology, finance, procurement, communications and regulatory engagement.

Interestingly, many of the skills in these last two categories are included in the latest Scarce Skills List for 2014 as published by the DHET (RSA, 2014a). It is estimated that 62 of the occupations listed in the 100 scarcest occupations

in South Africa will also be needed for the shale gas industry.³⁹ Importantly, the scarce skills that have been identified by the DHET publication (RSA, 2014a) cover the full spectrum of levels from the professionally qualified to the artisan and labourer. From the Australian report on unconventional gas (ACOLA, 2013), the scarce skills identified have been categorised in terms of the implementation of the gas extraction process. The categories are construction skills and operational skills, where construction skills relate to setting up the sites for the rigs to operate from and operational skills refer to the skills needed in the operation of the rig itself.

From a drilling perspective the following specific skills are necessary in the development stage:

- Engineers for planning and supervising drilling, completion and production operations and with a background and experience in drilling, completion and production, geology, reservoir and environmental engineering, etc. as well as in operations.
- Construction engineers for supervising well-site construction, and well-site engineers from the various service providers, as for example, for mud logging, cementing, formation evaluation, etc.
- Well site and labour staff, construction staff, rig crew, skilled labour of service providers, e.g. operators for formation evaluation, operators for cementing jobs, etc., truck operators, mechanics and electricians.
- Skilled workers required also include plumbers, pipefitters, steam fitters, cement masons and concrete finishers, industrial machinery mechanics, fracture stimulation crews, and petroleum pump operators.
- Semi-skilled workers include welders, inspectors, and testers.

Another important point made in ACOLA (2013) is that although the lifetime of a hydraulic fractured well is short, the operating crews move from well to well, not unlike a manufacturing process, so the process is not transitory but persists over the life of the project. Consequently, the demand for skills is rig-dependent and will be sustained over the life time of the resource so it is not a short-term phenomenon.

The skills sets mentioned to date relate primarily to the shale gas extraction process and site establishment. The consequence of developing shale gas to any significant extent in an area like the Karoo is that there will be

³⁹ The process for developing the DHET Scarce Skills List (RSA, 2014a) is to ask employers to identify what they see as scarce skills when they submit their Annual Workplace Skills Plan. Consequently the scarce skills identified reflect current perceived skills shortages rather than the result of a formal quantitative survey. Nor does it take any future needs into consideration such as those required for shale gas development.

additional knock-on effects in the building industry, the hospitality industry, the health sector and the retail sector to mention a few. Other than in the health sector, it is assumed that the additional jobs created in the other sectors will not create a further scarcity of skills.

In Section 5 of this report, it was proposed that baseline studies of the hydro-geology/geophysics, the groundwater resources and the ecosystems of the Karoo need to be carried out. These projects will require knowledgeable people in all these areas of study which will add to the skills challenge. In addition, it is not just the lack of skills that will be a challenge but also the lack of local instrumentation needed to undertake the studies.

Regulatory skills are another area that will be required for successful shale gas development. In order to ensure minimum impact on the eco and hydro-systems in the Karoo, it is anticipated that the operating licences that will be issued will have very strict requirements in this regard. It will be necessary to have adequate regulators in the various levels of government, both in terms of numbers and knowledge, to ensure that the licence requirements are being met.

6.3.3 Quantification

There is very little published work available on the numbers of the different skills sets needed for shale gas development. Further, until the volume of the shale gas resource is finalised, it will be difficult to firm up the number of jobs that will be created and as result the skills required.

However, Shell (2014) presents an overview of the number of skills needed in the future for both the onshore and the offshore upstream businesses in South Africa (Table 6-2). From the data presented, it is not possible to separate out the numbers in different skills categories. The data show a 13-fold increase in manpower demand over the ten-year period 2020 to 2030, with the largest increases in the Subsurface, Engineering and Vocational categories, which are either already in short supply or not being produced in South Africa.

Table 6-2: Onshore skills overview of manpower demand

	Year		
	2020	2025	2030
Subsurface	102	726	1 722
Engineering	305	2 034	4 429
Vocational	305	2 034	5 167
Functional	203	436	984
Total	915	5 230	12 302

Source: Shell (2014)

With respect to drilling, the total number of jobs that would be created, lies between four and 31 direct jobs per well. Other studies have predicted that 11 600 to 28 000 new jobs will be created over a 25-year period in South Africa (Decker, 2013; the dti, 2014). The options to establish such a skill repertoire in South Africa are to develop the skills within the country, to bring the necessary skills from outside into South Africa or to send domestic people abroad for training and to gain field experience.

With the current concerns associated with the MPRDA, it is anticipated that the offshore sector will develop at a slower rate than was initially envisaged. As a result the growth in the skills demand may not be as rapid as shown in Table 6 2.

Were one to assume the Karoo resource is 20 to 60 tcf (e.g. with the approximate lower end (20) after Geel *et al.* (2015), and an upper end (60) based on an approximate average between the medium (50) of Decker and Marot (2012), and the value (72.5) derived by Cole (2014) – See Section 4), then extrapolating based on the data presented in the ACOLA report, the job opportunities could be in the range of 3 000 to 10 000 for those directly involved in the shale gas extraction process. No attempt has been made in this report to quantify the demand for groundwater monitoring specialists, water analysts, regulators or communications experts. Neither has any estimate been made of the amount and cost of analytical equipment that will be needed for both the baseline studies as well as the monitoring programmes.

6.3.4 The Status Quo for Scarce Skills in South Africa

Of the scarce skills identified in Shell (2014), those relating to geology and geophysics are currently being produced by tertiary education facilities in South Africa, but the focus is on hard rock geology, rather than related to oil and gas. Consequently, while qualifications providing theoretical requirements for careers as a production geologist, exploration geoscientist, and geophysicist are offered in South Africa, due to the limited scale of the upstream industry in the country there are few opportunities to obtain practical experience in the oil and gas sectors.

The Upstream Training Trust (UTT) was formed under the auspices of the PetroSA in 1997 to utilise the funds generated from companies licensed to participate in the South African off and onshore search for oil and gas. Exploration and production licensees are required, in terms of their licence agreement, to contribute to the UTT annually. The UTT funds are used to provide bursaries to students wishing to study in the fields of natural sciences (geology and geophysics), engineering (all fields) and technology (mathematics or information technology). These studies can be pursued at any of the South African universities offering these programmes.

Essentially, none of the skills relating to the exploration and production of oil and gas are being produced in South Africa currently. By way of example, there are no established tertiary education programmes to produce the scarce skills identified in Shell (2014) such as well engineers, petroleum engineers and reservoir engineers. (A study of the workforce implications of implementing a shale gas industry in USA is worth noting.⁴⁰) In addition to all the upstream skills needed to implement shale gas development, the specialists needed for groundwater monitoring and water analysis are also in short supply. There is also a serious shortage of the necessary number of competent regulators across the three levels of government. At present there are no formal training and development programmes or centres of excellence to equip people with these skills. This then presents an opportunity that could lead to an improved understanding of the systems involved and the mechanisms in operation which will assist with and lead to improved buy-in to the exploitation of shale gas.

Given the scarcity of skills in South Africa, a number of initiatives have been launched in order to identify what the scarce skills are and to suggest how the gap can be closed. In the last five years or so, the DHET has been encouraging universities and universities of technology (25 in total) to increase the production of engineering graduates, technologists and technicians via a variety of means. Various public-private partnerships have been established to grow the ranks of artisans across the board by way of apprentice programmes. Usually these are run in conjunction with the Sector Education Training Authorities (SETAs) through the technical and vocational education and training colleges (50 in total).

Two recent projects that have considered the issue of scarce skills need to be noted. They are:

- 1 Scarce Skills for and through the Strategic Infrastructure Projects (SIPs) (DHET, 2014).
- 2 Operation Phakisa Report for the Ocean Economy (RSA, 2014b).

As part of the implementation of the NDP, 18 SIPs have been established, covering a wide range of issues and geographic areas and will need a variety of skills in order to be implemented successfully. Given the existing shortage of the skills, the DHET launched a study to identify the skills requirements for the different SIPs (DHET, 2014).

The DHET report (DHET, 2014) develops the shortages of skills based on the Organising Framework for Occupations and does not present a consolidated view of all categories and so it is difficult to extract the

⁴⁰ <http://www.shaletec.org/docs/NeedsAssessmentwithcoverSW.pdf>.

number of shortages specifically for the shale gas industry. However, an excellent approach for establishing the shortage of scarce skills for the shale gas industry would be to adopt the same approach and modelling methodology used in this DHET report (DHET, 2014). Interestingly, it is estimated that of the 88 occupations listed in the DHET Scarce Skills List, 78 will also be impacted by the shale gas industry if it takes off.

Operation Phakisa (RSA, 2014b) is the implementation of the Big Fast Results Methodology developed by the Malaysian government to achieve significant government and economic transformation within a very short time. The project has been implemented initially in two sectors, the ocean economy and health. The methodology focuses on bringing together key stakeholders from the public and private sectors for intensive engagement in collaboration sessions called laboratories (or labs).

In the Ocean Economy Project, four laboratories were identified as priorities, one of which is the Oil and Gas Exploration laboratory. Although this laboratory focused on developing offshore resources, the outcomes relating to scarce skills and skills development need to be taken into consideration for onshore shale gas development because of the similarity in skills needed.

Two initiatives under capability development were identified, viz. D1–develop/implement skills strategy roadmap; and D2 – develop capability for sub-surface research and data gathering. In terms of the timing for implementation, both these initiatives are planned for Phase II – medium term, with first results in 2019. Initiative D1, the skills strategy roadmap, is scheduled to start in 2016.

6.3.5 Matters of Concern Relating to Skills Development in the Short/Medium and Long Term

In 2012, the total number of engineering graduations, including engineers, technologists and technicians, including artisans, was 9 132 (DHET, 2014). It is clear that South Africa will not have the additional engineering skills needed to support the shale gas industry. The skills position is made worse when it is recognised that in order to implement the SIPs, the DHET has estimated there will be a shortage of 25 000 skills sets overall. Most of these skills sets (about 88%) will also be required by the shale gas industry

In order to address these issues of scarce skills, careful and urgent attention must be given to the following matters:

- 1 To initiate the shale gas industry in South Africa, many of the required skills for the upstream sector will need to be imported. This implies that the Department of Home Affairs (DHA) will need to develop a streamlined, enabling process that facilitates the entry of people with such skills.

- 2 Notwithstanding the need to import skills to initiate the shale gas industry, the participants in the industry need to maximise the use of local skills at all times and should embark on skills and knowledge transfer programmes to upskill local workers as quickly as possible. One option is to place more emphasis on providing 'on the job' training and development.
- 3 Natural scientists who qualify through local universities will not have had exposure to the geology and work associated with shale gas and hence it is important that prospective licensors for shale gas development in South Africa be required to send these specialists to their operations elsewhere in the world to accelerate their learning around the issues of shale gas development. This will require companies licensed to carry out shale gas development in South Africa to send appropriately selected local individuals to be trained to operate all the aspects of a drilling rig.
- 4 A detailed study, coordinated by the DHET, using their modelling approach developed for the SIPs, should be carried out in order to quantify the skills required for shale gas development until at least 2030. Close collaboration needs to be established and maintained between this proposed study and the Capability Development initiatives proposed by the Oil and Gas Exploration Lab of Operation Phakisa.
- 5 If it is shown that the unconventional gas resource in South Africa has sufficient potential to create a new industry with a lifetime of 20 to 30 years, the results of the detailed study above need to be used to plan the tertiary education programmes that will support and grow the scarce skills for this industry at all levels.
- 6 Given that the increased number of licences issued to explore and produce oil and gas in South Africa will increase if shale gas development goes ahead, then the funds transferred to the UTT will increase and these funds can then be used to fund some of the students in these new programmes.
- 7 There should also be a study done to understand the impact on a broader range of skills and occupations that will be impacted if shale gas development begins in the Karoo in earnest. These skills and occupations will cover a wide range of skills from drivers and manual labourers through to those associated with the building, hospitality and health industries.
- 8 The number of regulators will need to be increased and their skills enhanced in order to give effect to the licence regulations and all training must be certified to industry or international standards.

- 9 The SAOGA works closely with businesses, schools, universities and the government and further relationships for oil and gas programmes are being built with foreign universities, e.g. Robert Gordon in the UK and such initiatives need to be encouraged.





7 CONCLUSIONS AND RECOMMENDATIONS



Based on the key findings summarised below, a consolidated set of recommendations aimed at ensuring the technical readiness of South Africa to support a shale gas industry is presented in the next section.

7.1 Key Findings

7.1.1 International Perspectives

Based on a comprehensive review of shale gas developments in other countries, many lessons can be learned. South Africa urgently needs to assess its technically recoverable shale gas resources given the importance of security of domestic energy supply. The country must commit to a balanced long-term shale gas exploitation strategy based upon the four elements of sustainability, viz. security of supply, efficiency of extraction, environmental protection and societal communication. It is important that South Africa builds upon the shale gas and shale oil developments that continue to take place in the North America (USA and Canada), Europe, Asia and Australia, fully utilising the wealth of published evidence made available by credible scientific bodies. Following the examples of countries such as the UK, Germany, Poland, Canada and Australia, South Africa must conduct its own baseline studies in order to facilitate the unambiguous evaluation of environmental impingement should shale gas exploration and extraction proceed. The country must also expand its interaction and collaboration with the world's leading professional and academic institutions to facilitate knowledge transfer, establish state-of-the-art working protocols and conduct regional, as well as site-specific, environmental monitoring. Space must be opened for greater civil society participation within ongoing processes. In effect there is an urgent need to open up the process of shale gas development to a wider sector of society than has been witnessed thus far.

7.1.2 Exploration to evaluate the Shale Gas Potential of the Karoo

Presently, the Karoo shale gas is a resource with approximately 19 to 23 tcf of available free gas across an area of approximately 79 - 92 000 km². However, the 3-D geology of the Karoo is poorly known, and remote geophysical sensing and deep-cored drill-holes will need to be implemented during a first exploration phase to determine subsurface

distribution of gas-shales and location of 'sweet-spots' to allow for greater accuracy in the determination of the total potential recoverable amount of shale gas in place. Limited multi-directional hydraulic fracturing at three to five pads will be needed during a second exploration phase to evaluate the retrieval success of the shale gas and how efficiently the gas can be harvested to determine its economic return, and its status as gas reserve. During both phases of shale gas exploration, quantitative knowledge about groundwater resources of the Karoo will vastly improve. For both these stages of shale gas exploration, there are local skill shortages and lack of equipment and basic infrastructures in South Africa.

South Africa has a history of inadequate controls when it comes to externality costs related to mining and abandoned mines. This must be avoided at all costs in the case of shale gas exploitation in the Karoo, starting right from the first exploration phase.

7.1.3 Legal, Regulatory and Governance Aspects

The EIA procedure together with the EMP process, driven by the DEA and DMR under NEMA and the MPRDA respectively, are central in ensuring the success of the upstream to downstream shale gas enterprise. However, neither of these two processes provides for carrying out a SEA. The SEA recently commissioned by the government must be strongly supported to determine the most economically, socially and environmentally optimal gas source to be exploited for the country. Such a study should identify alternative sources of both conventional and unconventional sources and weigh up the costs and benefits to South Africa of each.

Upstream to downstream shale gas activities require the intergovernmental collaboration and cooperation of a wide range of national government departments, as well as potentially affected provinces and municipalities ("Co-operative Government" Chapter 3 of the Constitution; Intergovernmental Relations Framework Act, *Act 13 of 2005*). National government departments include: DMR, DWS, DEA, DoE, DST and others. Hence it will be necessary to establish both an inter-agency statutory body whose overall function will be to promote and facilitate the development of the onshore and offshore oil and gas industry in South Africa, and an independent and inter-departmental monitoring committee which includes both government representatives and non-government participants to ensure the effective and transparent implementation, monitoring and compliance with existing laws and regulations applicable to shale gas extraction. This process will be a prerequisite for an open and transparent monitoring of shale gas development in the Karoo, holding both industry and government accountable.

It is estimated that an initial exploration programme (including evaluating seismic activities and gas harvesting potential) will last five to ten years. This provides an opportunity to carry out and conduct vital baseline studies, as well as assess technical and human capacity needs. It will be necessary to ensure that the granting of exploration licences be conditional on the carrying out of further independent feasibility, social and environmental studies prior to the issuance of a production licences. It should be made clear that granting exploration licences does not automatically assume the granting of production rights, but that this will depend on the above-mentioned independent studies.

Even if South Africa were considered to be technically ready in the narrow sense to undertake shale gas extraction, there are numerous social, political and environmental management hurdles to be overcome if the shale gas enterprise is to go ahead. This will require that the precautionary principle, a fast emerging and central principle of international environmental law, recognised in South African case law, be incorporated in the NEMA in the principle that: "[A] risk-averse and cautious approach is applied, which takes into account the limits of current knowledge about the consequences of decisions and actions". Such an approach should inform all decision-making affecting shale gas exploitation and remain central to the evolving legislative and regulatory framework being driven by continuous amendments to the MPRDA, NEMA, Spatial Planning and Land Use Management Act and other relevant legislation towards embedding the precautionary principle across the entire shale gas development landscape.

7.1.4 Issues of Water, Sand, Air and GHG Emissions

Water requirements for hydraulic fracturing and the likely flowback of returned frack-fluid and production water, which should preferably be recycled, are unlikely to be determined precisely until after trial hydraulic fracturing is undertaken during exploration Phase II. Therefore it is not certain whether the water requirements for the production phase might be less than say 1.5 l/s, which could perhaps be supplied from local groundwater sources, or as high as about 10 l/s. In both cases, the preferred sources of water supply would be deep saline aquifers, although the importation of water by pipeline or truck is an option. The availability and yields of deep saline aquifers must be determined during early exploration processes. In addition, the 3-D geometry of dolerite dykes and sills and the possible presence of kimberlite and hydrothermal pipes, must be mapped in detail during the entire exploration phase, particularly with respect to determining risks associated with potential fluid escape conduits. Similarly, the disposal of excess flowback should also be investigated. Licences for water use and the disposal of flowback fluids would be required and reserves may also have to be determined in accordance with the NWA.

Robust strategies must be implemented to determine source apportionment of CH₄ emissions and to quantify local atmospheric CH₄ concentrations before and after the start of exploration. For example, possible natural gas production rates in hot springs and water-wells and agricultural emissions from livestock enteric fermentation and manure management, point source emissions from landfills and wastewater treatment facilities will all need to be quantified. This will require continuous ground and airborne monitoring of CH₄ leakage to determine GHG footprints of all sources across the Karoo.

Proppants used for hydraulic fracturing are likely to be sourced from local suitable dune-sand deposits which exist in South Africa and along its coastal margins, but these are mostly environmentally sensitive and often in protected areas. Environmental (land use, water needs) and health issues (silicosis, industrial accidents) associated with sand mining, processing, and transportation are well understood and for shale gas exploitation this must be continuously monitored if such material is transported across the Karoo.

7.1.5 Potential Impacts on Astronomy Activities

Hydraulic fracturing operations, including supporting activities, remain a significant risk to the scientific performance of the SKA. Part of this risk is as a result of the uncertainty arising from lack of information on specific hydraulic fracturing activities such as deployment strategies, site-specific analyses, equipment usage (characterised in terms of EMI), and supporting activities.

The extreme sensitivity of the SKA means that even the weakest of human-made radio signals is detectable at some level, and in some part of the radio frequency spectrum across which the SKA will operate. To minimise the potential impact of this risk, careful management and coordination with stakeholders, acting in concert with regulatory and legislative requirements (such as AGA Act, Act 21 of 2007), is needed.

Based on assumptions made regarding the type of equipment to be used during hydraulic fracturing operations, a buffer zone of 30 km should be adopted around each SKA station, inside which no hydraulic fracturing activities should take place. A secondary buffer zone of 50 km around each SKA station should be adopted, inside which (i.e. between 50 km and 30 km from an SKA station) potential hydraulic fracturing operations should be assessed in detail and, if required, conditions imposed prior to any such activities taking place. Prior to any exploration activities commencing, applicants for shale gas exploration in the Northern Cape province should be required to work together with the Astronomy Management Authority to identify exploration sites appropriate both to SKA South Africa and the licence application that would not pose a detrimental risk on the scientific performance of the SKA.

A degree of uncertainty has been considered in identifying appropriate buffer distances. This uncertainty could be reduced by undertaking the following:

- 1 Determination of the full range of equipment to be used, and supporting activities, in the site establishment, construction, operation and decommissioning of hydraulic fracturing sites for each of the various prospective licence applicants.
- 2 Radio frequency measurements and analysis to characterise the EMI from any relevant equipment if no appropriate national or international standards exist. This may require field work at representative sites operated by the licence applicants.
- 3 Determination of a detailed deployment (including site selection) and operations programme, to be used as input into an impact analysis.

However it should be noted that most of the SKA and the Sutherland Observatory fall within a region where the gas-shale resides less than 1 500 m below surface, and is therefore unlikely to be of interest for shale gas harvesting, because hydraulic fracturing should be banned at such shallow levels.

7.1.6 Socio-Economic Impacts of a Shale Gas Industry

Considerable emphasis is being placed globally on both the vertical and horizontal coordination across government, such as regional, federal and state coordination, as well as within unitary models similar to ours in South Africa. This is also aligned to the growing global recognition of the need for effective legislation and regulatory frameworks for monitoring and mitigation of potential risks associated with the shale gas industry.

In addition, the need for assessing risks and capacitating government and society as a whole to better assess, quantify and ultimately manage, both the concomitant externality and opportunity costs of pursuing shale gas development as a country need to be taken into account. In the current context of the Karoo, it is uncertain if the process to date reflects this growing consensus approach to shale gas development.

In particular, there is a gap between the ongoing and wide reaching legislative and regulatory reforms by government (i.e. in response to shale gas development) and the need for an appropriately wide-reaching public consultation and awareness programme in the Karoo. This absence of a dedicated public participation framework will present further fractures in a community gradually being divided over a set of competing interests, with the ever-growing expectations of a shale gas 'utopia' for the poor unemployed and the prospect of a shale gas 'wasteland' for those who fear they have everything to lose in the Karoo.

To date, much of the focus at a national level has centred on the broader economic impacts and benefits to the national economy and energy balance, but inadequate consideration has been given to the localised effects of these pronouncements within the receiving environment.

7.1.7 Rationale and Methodologies for Baseline Studies in the Karoo

Some impacts of a shale gas industry will be immediate and at a local level at drill and gas-wells. Others will be more long term and more extensive across the Karoo. Of major concern is the consumption of water and management of potable ground and surface water, as well as the integrity of ecosystems, potentially contaminated directly by hydraulic fracturing and indirectly through flowback water that may be recycled by injecting it back into the shale during subsequent hydraulic fracturing operations.

New roads, gas pipes, water pipes and heavy truck traffic may fragment the vast open Karoo and change the aesthetic value of its landscapes. Migrant labour will also impact the environment and the social functioning of this sparsely populated region, albeit with densely, low-income populated townships. Landscape fragmentation would be especially dire in an environment where rainfall events are patchy and unpredictable. It is important to establish adequate micro-seismic networks to detect locate and distinguish those triggered from natural micro-seismicity. All these issues need thorough documentation of the Karoo as a natural laboratory and the establishment of its natural state so that accurate scientific data and observations can be used as a standard against which to measure the degree of any potential pollution and disturbances during and after shale gas exploration and possibly exploitation.

There is perhaps a five-year window of opportunity to gain a firm understanding of the present state of the Karoo and its underground water systems and surface environments, and to use this to establish a forensic baseline across the Karoo. Without such a baseline, underpinned by a good understanding of the hydro-geology/geophysics, any contamination of groundwater or destruction of ecosystems related to hydraulic fracturing and harvesting of gas cannot be determined with sufficient accuracy or proven beyond reasonable doubt, rendering litigation around damage and externality costs of exploitation of the gas almost impossible. In the absence of reliable baseline information, it would be near impossible to blame any such incidents on gas extraction activities. It is therefore critical to establish baseline conditions before drilling and to use multiple lines of evidence to better understand gas migration and possible chemical pollution. To achieve this, a mutual trust system, linked to 'honest brokers', will need to be developed that will allow neutral research and citizen scientists to gain access to a wide variety of private, communal and government land, and scientific data.

South Africa must at the same time create the necessary regulatory, monitoring and enforcement capacity, rooted in reliable baseline data, to give a robust sense of security to citizens that extraction of shale gas will not cause long-term damage and unanticipated externality costs. To facilitate effective communication, government must endeavour to create the infrastructure for efficient local internet access for all Karoo communities, alongside a dedicated public participation programme with poor communities who currently lack internet access to create a collaborative commons.

The know-how, technology, and most equipment required for virtually all needed scientific baseline studies, and continuous monitoring thereafter, are not presently available at South African academic research institutions or at its science/research councils. To address these shortcomings, it is therefore recommended that South Africa invest in academic and professional institutions to develop the necessary capacity, and to establish an applied and experimental 'Karoo Shale Gas Laboratory and Training College' where relevant skills development can be enhanced.

7.1.8 Well Construction and Closure

Shale gas development is a manufacturing process unlike conventional oil and gas developments on and off shore. Consequently, it is necessary to build a robust field development model to understand and plan all relevant aspects of establishing the technical capacity to develop the field, including the environmental and economic impact. It is necessary to perform pilot field development work as part of the exploration phase to establish a local technical baseline as input to the model (water usage, resource requirements, and emissions) within six to 12 months. Without this information, strategic decisions and negotiations of production licensing agreements with potential operators will not be efficient. Developing a rural technical college (Refer to Section 7.1.7 above) linked to a controlled hydraulic fracturing site and gas research centre of excellence, can serve as centre of ongoing modelling in the field.

General problems related to shale gas drilling relate to factors such as, *inter alia*:

- The large number of the production sections drilled with oil-based mud.
- Operators need to present detailed water management plans.
- Due to the quality requirements, many constituents of water, such as TDS, calcium and other solid materials would have to be reduced to certain limits.
- The API and ISO standards for casings should be evaluated for local circumstances.

- CH₄ spills and groundwater contamination must be carefully managed.
- Operators should follow special regulations to ensure well-integrity under high pressure.
- The requirement for proper quality cement used for casing.
- The legislation for well closure must be defined carefully to ensure a proper sealing of the well after the production period.

Special challenges related to shale gas drilling in South Africa include issues relating to the provision of adequate number of rigs, availability of casings, and the development of the necessary skills base within the country.

Ensuring well-integrity must remain the highest priority to prevent short-term air pollution, and long-term (>50 years) contamination of the critical zone (ecosystems, soil, water). There must be lifelong instrumentation (processes) in place to monitor 'closed wells' and there is a need for clarity on severance or well-retirement tax, irrespective of a reported/immediate damage.

7.1.9 Distribution and Exploitation of Shale Gas

The South African gas market is potentially large. Whilst the shale gas opportunity is being assessed (five to ten years), there is an opportunity now to develop anchor markets based on CNG and LNG imports. Gas-to-power projects are essential for this development. There is a strong commercial appetite for investing in the requisite infrastructure. The limiting constraint is national energy policy and regulation. This shortcoming needs to be addressed immediately. This requires that a revised IRP for electricity (IRP 2010 update) should be adopted by Cabinet, and the role of natural gas re-emphasised in the light of changed conditions since that modelling was undertaken. At the same time, the DoE should release the GUMP, and its IEP, and a 'whole of government' approach should be implemented forthwith to ensure the effective use of natural gas within South Africa's energy economy.

South Africa needs to accelerate its adoption of public-private partnerships for large-scale complex infrastructure projects which will require a rethink of public procurement protocol. Market development is entirely predicated on the price of gas at point of use. Aspirations to develop export-oriented products, specifically, need to be checked in detail against the likely well-head cost of shale gas, transmission and conversion costs. The country should prioritise research which demonstrates the overall environmental costs and benefits of the shale gas value chain.

7.1.10 Capacity and Skills Development

In order to address the issues of scarce skills, it is proposed that careful and urgent attention be given to a range of issues in order to address the major challenge presented by the shortage of appropriate skills for the shale gas industry. Initially all required skills for the upstream shale gas sector will need to be imported, which will require a mixed approach, divergent from 'business as usual' if risks are to be mitigated and benefits accrued through the sector. This will require a scaled approach with clearly defined long, medium, and short-term strategies for developing the necessary indigenous skills across the value chain. Emphasis will need to be placed on both government and industry requirements, with a special emphasis on monitoring and environmental capacities across society.

In the short term, the development of local skills will require operators to provide 'on the job' training and development for people when they leave secondary and tertiary education institutions. This will require that companies licensed to carry out shale gas development in South Africa need to contribute in various ways to the up-skilling of these entry-level persons.

A detailed study involving all role players, including DHET, Phakisa, higher education institutions, etc., should be carried out in order to quantify the skills required for shale gas development until at least 2030. These interventions should be partially funded by companies involved in shale gas exploitation. It is also critical to ensure that the number and skill of regulators needed to monitor the licence regulations be evaluated.

The globalisation of shale gas and its rapid expansion has placed pressure on a finite global reserve of skills in the oil and gas sector. Long-term strategies must take this into consideration and should cut across the emerging regional (onshore and offshore) oil and gas industry. Shale gas, whilst the focus of this report, cannot be isolated from the broader oil and gas sector especially in the SADC and African context.

7.2 Recommendations

A consolidated set of recommendations emanating from these investigations and aimed at ensuring the technical readiness of South Africa to support a shale gas industry is presented in this section. As indicated in the summary of these recommendations presented in the Executive Summary, not all of these recommendations for action lie directly within the area of responsibility of the Department of Science and Technology and a number are clearly for the attention of other government departments. All of the recommendations however are considered to be directly relevant to the mandate given for this study.

Determination of the Shale Gas Reserve

- 1 The foremost priority for South Africa is the accurate determination of the quantity of potentially recoverable shale gas. It is recommended that the DMR should assess the option of dividing exploration licencing into two phases (Phase I and Phase II), linked by continuous environmental monitoring. In this way, exploration is detached from production via continuous environmental impact analyses that can account for the environmental and operational baseline data obtained during exploration Phase I.
 - During Phase I, the subsurface distribution of gas-shales and location of 'sweet-spots' must be determined to establish with greater accuracy the total potential recoverable shale gas. This will entail remote geophysical sensing and deep-cored drill-holes. Standard surface exploration and seismic data must be acquired by means of passive technology and not through induced seismicity using explosives. Identifying deep saline aquifers will be a prerequisite.
 - Hydraulic fracturing marks the start of exploration Phase II, before and during which a new EIA should be conducted, inclusive of 3-D analyses based on continuous down-the-hole data acquired during the drilling of vertical wells. No hydraulic fracturing should be permitted within 1 500 m of the surface until hydraulic fracturing and casing technologies improve to the point where it can be clearly demonstrated that such technologies are able to prevent groundwater pollution caused by rock and technology failure. (Failure to adhere to such restrictions may represent a high-risk approach unless the geological baseline studies can provide clear evidence that there is a minimal risk associated with upward fracture propagation during hydraulic fracturing at shallower levels.) Limited multi-directional hydraulic fracturing at selected well pads will be needed during a second exploration phase to evaluate the retrieval success of the shale gas and how efficiently the gas can be harvested to determine its economic return, and its status as gas reserve. Following the exploration phases, abandoned wells must be properly closed using best sealing practices.

Policy, Regulations and Licensing

- 2 Immediate steps should be taken to establish a new, or strengthen an existing, government agency whose overall function is, inter alia, to enable and facilitate the development of the shale gas industry in South Africa. This task arguably falls within the responsibilities of the Interministerial Committee on Hydraulic Fracturing. This designated agency must coordinate licensing and monitoring functions in consultation, as necessary, with the relevant government departments.

- 3 As a matter of priority, a review of all pertinent policies and plans which impact on the development of shale gas in South Africa should be undertaken with the aim of ensuring their effective alignment across all government sectors.
- 4 Steps should be taken to ensure that all regulations relating to shale gas accommodate the ongoing rapid technological developments in the exploitation of such gas and include requirements for the adoption and implementation of internationally recognised state-of-art best practices across the technical, environmental, social, economic and political spheres.
- 5 The award of an exploration licence should require the operator to perform pilot field development studies to establish, within six to 12 months of the award of the licence, a local technical baseline as input to an open source model in order to provide the necessary information to be used in reaching decisions on the production licence agreements.
- 6 The award of any licences for shale gas development must require that such developments do not prejudice the sustainable use of potable surface and groundwater, and must not compete with fresh water requirements of humans, animals and ecosystems. In the context of precautionary principles, local water licence holders should be required to use deep saline water reservoirs where available. Compliance monitoring should be required and should be the responsibility of the agency referred to in Recommendation 2.
- 7 Any exploration licence awarded must include the requirement that a statistically significant number of vertical wells be constructed during exploration Phase I and that each must be subject to at least one full-scale trial hydraulic fracture at the start of Phase II to determine, *inter alia*:
 - Total water volume requirements and additives.
 - Flowback and produced water volumes and composition.
 - Gas and particulate emissions from each step in the well development process.

This will include the need for the agency referred to in Recommendation 2 to facilitate with the relevant government departments the awarding of licences relating to water and air quality.

- 8 Any exploration licence awarded must require that the information from the trial hydraulic fracture experiments at the start of Phase II, be made available to the DMR within 24 months of issuing the exploration licence and should include details relating to drilling to identify deep saline aquifers and reuse and disposal of excess flowback.

Baseline Monitoring

- 9 The DST, in consultation with other relevant government departments, should initiate, with urgency, a major project to undertake robust interdisciplinary, regional and local baseline studies to establish a body of knowledge on the *status quo* with regard to a range of issues, at this critical juncture, prior to commencement of shale gas exploration/exploitation. The initiation of baseline monitoring should form the basis of an ongoing monitoring network. This must include acquisition of both surface and deep terrestrial data. While it is recognised that there may be several organisations (e.g. SAEON) currently involved in baseline monitoring, it is necessary to coordinate these efforts and to extend the monitoring to below the surface. The DST should take the lead in convening or facilitating the convening of a public engagement event with active organisations to assess the status and level of ongoing activity in terms of studies contributing to baseline information.

Given the multi-disciplinary nature of the data required and the provision of a database that could inform research endeavours, the DST is identified as the lead department to oversee this task. The data collected should be archived in an open database management system to facilitate transparency and to foster research. It is emphasised that it is important for such monitoring to commence as soon as possible and to be put in place for a long period of time, as the Karoo presents a unique pristine environment in which to gather baseline data prior to the commencement of any shale gas development activities.

Field Development Model

- 10 Given that shale gas development is a manufacturing process unlike conventional oil and gas developments on and offshore, it is recommended that a robust field development model be established so as to understand and plan all relevant aspects of establishing the technical capacity to develop the field. Such an undertaking will require collaboration of multiple national departments since the proposed shale gas industry touches on numerous aspects of the physical space of the Karoo. DST should be the initiator of such a field development model, based on the outcomes of the recently initiated SEA, and should maintain custodianship as the lead government department in science and technology research. An initiative on the scale and significance similar to Operation Phakisa and the Oceans Lab will provide a platform from which to gather input and to build a framework upon which to build.

Infrastructure

- 11 An assessment of the economic implications of shale gas development for South Africa must be undertaken to critically assess the supply-

demand situation. This should include an assessment of the potential of shale gas to significantly impact on the national energy requirements. It will be necessary to commit public sector funding to gas transmission and distribution infrastructure in order to develop gas markets which are currently based on imports. Previous such assessments should be reviewed in the light of recent economic developments in the oil and gas industries. The GUMP must be incorporated into the national plan for the implementation of a shale gas industry and such information must be incorporated into the field development model.

Public Consultation

- 12 It is recommended that the relevant national departments (DST, DMR, DEA and DWS) implement a comprehensive public consultation and engagement process with local communities in the Karoo as a matter of considerable urgency. This includes the need for an evidence-based information sharing programme, which is independent of prospective operators and parties with other sectional interests. It should give due attention to the prevailing environmental and social concerns, expectations, and interests of all local communities. Such consultations should include addressing issues relating to the principle of local and regional beneficiation and participation in shale gas development in the Karoo Basin.

Human Capital Development

- 13 Urgent steps need to be undertaken by the relevant government departments in collaboration with industry, to coordinate all skills planning initiatives in South Africa to develop a single, coordinated development plan for the shale gas industry. This should include appropriate education and training programmes for artisans, technologists, scientists and engineers at identified institutions. The plan should include a strategy to expand interaction and collaboration with the world's leading professional and academic institutions in order to facilitate knowledge transfer and establish state-of-the-art working protocols based on robust scientific and engineering methodologies. A first step would be to undertake a review of current education and training programmes available to assess the nature and applicability of current tertiary education qualifications in terms of the shale gas industry and to identify gaps. Following this study, it will be evident where efforts should be directed to support the shale gas industry.
- 14 Immediate and substantive investment should be made in the development of expertise and equipment capacity in resource exploration in consultation with the appropriate state and academic institutions and industry. The first step will require a national review to assess the availability of such equipment and skills. The outcome of

the review will indicate where new initiatives and investment should be directed.

- 15 To address the shortcomings in terms of skills and equipment, it is recommended that an applied and experimental 'Karoo Shale Gas Research Laboratory and Training College' be established. The purpose of this initiative would be to facilitate drilling experiments and hydraulic fracturing tests which will be carried out under controlled conditions, as well as providing an opportunity for the state and industry to attract competent researchers and mentors in order to develop local persons with the necessary monitoring skills to ensure a competent, transparent and compliant shale gas industry.
- 16 A review of the state of shale gas research in South Africa should be undertaken to provide a baseline from which to enhance local research capacity. The scope should be broad and embrace all aspects relating to the shale gas industry, including geophysical, socio-economic, engineering and other aspects.
- 17 Steps should be taken to strengthen the local research capacity to support the shale gas industry by establishing appropriate research chairs and/or centres of excellence of direct relevance to the shale gas industry.
- 18 In the short term it will be necessary to facilitate the importation of people with the required upstream/technical and regulatory skills to assist in the initial phase of the development of a shale gas industry and in the provision of the appropriate training programmes.

Astronomy

- 19 Any legislation that is introduced to have oversight of the shale gas industry must be fully aligned with the AGA Act. No hydraulic fracturing should take place within a 30 km buffer zone of an SKA site, and within a secondary buffer zone of 50 km, detailed assessments, with possible conditions, are required before hydraulic fracturing can proceed.





GLOSSARY



Term	Description
Abandoned well	A well that is not in use because it was drilled as a dry hole or has ceased to produce or for some other reason cannot be operated.
Annulus	The space between two concentric cylinders or pipes.
Aquifer	A subsurface water bearing geological strata which has high porosity and permeability that allows easy extraction of the water.
Artesian	Water bores in which the water surface is above ground level and the water flows.
Base load	The minimum amount of electric power delivered or required over a given period of time at a steady rate.
Blowout	An uncontrolled flow of gas (oil or other well fluids) occurring when formation pressure exceeds the pressure applied to it by the column of drilling fluid.
Borehole	The hole or shaft in the earth made by a well drill; also, the uncased drill-hole from the surface to the bottom of the well.
Casing	Pipe cemented in an oil or gas well to seal off formation fluids and to keep the borehole from caving in. Smaller diameter "strings" of casing are cemented inside larger diameter strings as a well is deepened.
Complete a well	To finish work on a well and bring it to productive status.
Conventional natural gas reservoir	A geological formation in which the natural gas is in interconnected pore spaces, much like a kitchen sponge, that allows easier flow to a well.
Downstream	A term used most commonly in the petroleum industry to describe post production processes (e.g. refining and marketing sectors of the petroleum industry).

Term	Description
Drilling rig	Usually a large-standing structure employing a drill that creates holes or shafts in the ground for purposes of accessing and producing natural gas or oil from subsurface deposits.
Exploration	The act of searching for potential sub-surface reservoirs of gas or oil. Methods include the use of magnetometers, gravity meters, seismic exploration, surface mapping, and the drilling of exploratory test wells.
Flaring	The controlled burning of natural gas that can't be processed for sale or used because of technical or economic reasons.
Flowback	Water used as a pressurised fluid during hydraulic fracturing that returns to the surface via the well. This occurs after the fracturing procedure is completed and pressure is released.
Formation	A body of earth material with distinctive and characteristic properties and a degree of homogeneity in its physical properties.
Formation water	Water that occurs naturally within the pores of a water-bearing rock formation. Oil and gas reservoirs have a natural layer of formation water that lies underneath the hydrocarbons.
Fracking	(Hydraulic fracturing) The fracturing of rock with a liquid under high pressure to create artificial openings and cracks in the rock to increase the rock's permeability.
Fracturing fluid	The primarily water-based fluid used to fracture shale. It is basically composed of 99% water, with the remainder consisting of sand and various chemical additives. Fracturing fluid is pumped into wells at very high pressure to break up and hold open underground rock formations, which in turn releases natural gas.
Fugitive emissions	A primary air quality concern from natural gas production (including shale gas) is leaking and venting throughout the supply chain. These fugitive emissions a potentially result in releases of methane, the primary constituent of natural gas and a potent greenhouse gas. In addition, fugitive emissions of natural as can release volatile organic compounds and hazardous air pollutants, according to the study.

Term	Description
Gas turbine plant	A plant in which the prime mover is a gas turbine. A gas turbine consists typically of an axialflow air compressor and one or more combustion chambers where liquid or gaseous fuel is burned and the hot gases are passed to the turbine and where the hot gases expand drive the generator and are then used to run the compressor.
Gas-in-place	The volume of gas in a reservoir at any given time, calculated at standard temperature and pressure conditions, that includes both recoverable and non-recoverable gas.
Grid	The layout of an electrical distribution system.
Groundwater	All subsurface water as distinct from surface water. More specifically, the part of the subsurface water that is in the zone of saturation.
Horizontal drilling	Drilling into the earth in an initially vertical direction, followed by a change in drilling direction to the horizontal at a suitable depth.
Hydraulic fracturing	('Fracking') The fracturing of rock with a liquid under high pressure to create artificial openings and cracks in the rock to increase the rock's permeability.
Independent power producer	Corporation, person, agency, authority, or other legal entity or instrumentality that owns or operates facilities for the generation of electricity for use primarily by the public, and that is not an electric utility.
Manufactured gas	A gas obtained by destructive distillation of coal or by the thermal decomposition of oil, or by the reaction of steam passing through a bed of heated coal or coke. Examples are coal gases, coke oven gases, producer gas, blast furnace gas, blue (water) gas, carburetted water gas. Btu content varies widely.
Market-based pricing	Prices of electric power or other forms of energy determined in an open market system of supply and demand under which prices are set solely by agreement as to what buyers will pay and sellers will accept. Such prices could recover less or more than full costs, depending upon what the buyers and sellers see as their relevant opportunities and risks.
Microseismic	A faint movement of the earth.
Mud (drilling)	Fluid circulated down the drill pipe and up the annulus during drilling operations to remove cuttings, cool and lubricate the bit and maintain a desired pressure in the well.

Term	Description
Natural gas	A naturally occurring mixture of hydrocarbon and non-hydrocarbon gases beneath the surface, the principal component of which (50-90%) is methane.
Oil shale	Shallow shale containing oil. Mined by conventional methods and retorted at high temperature at the surface to distill the contained oil, or by in situ treatment with steam. Should not be confused with "shale oil", which is oil contained in the natural gas extracted from deep shales.
Operating costs	Costs associated with a company's operations that are deducted against revenue to determine profit.
Permeability	The ability, or measurement of a rock's ability, to transmit fluids, typically measured in darcies or millidarcies.
Porosity	The interconnection of pores within a rock; also a measure of the flowability of a fluid within a rock that contains pores.
Produced water	Naturally occurring water found in shale formations; it generally flows to the surface during the entire lifespan of a well, often along with natural gas.
Proppant	A granular substance, often sand, that is mixed with and carried by fracturing fluid pumped into a shale well. Its purpose is to keep cracks and fractures that occur during the hydraulic fracturing process open so trapped natural gas can escape.
Reserve	Those reserves recoverable under current technology and present and anticipated economic conditions. Also a term commonly used in reference to total proved reserves plus half probable reserves.
Reservoir	Rock strata that contains liquid or gas within its porosity; not a large void space or cavern under the earth.
Shale	A rock structure beneath the earth's surface formed from mud deposited by riverine, lake or marine systems over geological timescales.
Shale gas	Natural gas produced from shale formations.
Shale gas play	A set of discovered, undiscovered or possible natural gas accumulations that exhibit similar geological characteristics. Shale plays are located within basins, which are large-scale geologic depressions, often hundreds of miles across, which also may contain other oil and natural gas resources.
Slickwater	Hydraulic fracturing water whose properties (e.g. surface tension) have been modified through the use of additives.

Term	Description
Surface water	Water that is open to the atmosphere, such as rivers, lakes, ponds, reservoirs, streams, impoundments, seas and estuaries.
Tight gas	Natural gas found in low-permeability sandstones and carbonate reservoirs. The rock layers that hold the gas are very dense, preventing easy flow.
Unconventional natural gas reservoir	Coal bed methane, shale or tight gas, where the natural gas does not flow naturally to the well, but instead requires some form of extensive stimulation to generate economic flow rates.
Underground injection	Hazardous waste deposited by force and under pressure into an underground steel and concrete-encased shaft for storage or disposal.
Upstream	The sector of the petroleum industry involving exploration and production.
Well completion	A well where operations have advanced to a stage where it is ready to produce oil or gas.
Well pad	A temporary drilling site to prepare a targeted location for production. The well pad is the area of cleared land, which may be from one to less than five acres. The well pad is covered with lining material to prevent seepage into the ground and the drilling rig is constructed over the pad area. When the well is completed, the drilling rig is replaced by the well-head.
Well stimulation	A treatment performed to restore or enhance the productivity of a well.
Well-bore	The drilled hole or borehole, including the open-hole or uncased portion of the well.
Well-head	The equipment at the surface above the well.



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APPENDICES

APPENDIX 1: BIOGRAPHIES OF PANEL MEMBERS

Cyril O'Connor (CHAIR)

Professor Cyril O'Connor is a Senior Research Scholar in the Department of Chemical Engineering at UCT. He holds a PhD degree from the University of Cape Town and a DEng. from the University of Stellenbosch. He was the Director of the Centre for Minerals Research and was founder Director of the Centre for Catalysis Research. He is President of the International Mineral Processing Council, is a former Vice-President of the International Zeolite Association, is a member of the Executive Committee of the South African Academy of Engineering (SAAE) and is CEO of the South African Minerals to Metals Research Institute (SAMMRI). He is an Honorary Fellow and Fellow of the South African Institute of Mining and Metallurgy, a Fellow of the Royal Society of South Africa, UCT, the SAAE, the South African Institution of Chemical Engineering, International Union of Pure and Applied Chemistry and is a founder Member of ASSAf.

Stephanus de Lange

Mr Stephanus de Lange has been a hydrogeological consultant for the past 12 years. Hydrogeological experience has been mostly related to the mining environment. Although involved in all aspects of hydrogeology, experience in field work related to hydrogeology considered as trademark. A research assistant at the Institute for Groundwater Studies, the University of the Free State for the past four years and responsible for introducing students to field work with regard to gathering and compilation of general hydrocensus information, borehole drilling techniques, aquifer testing and tracer tests. Involved in research on the interaction between surface and groundwater as well as assessing hydraulic fracturing of the Karoo shales (Ecca Formation) and the impacts associated with hydraulic fracturing on shallow fresh water aquifers.

Maarten de Wit

Professor Maarten de Wit occupies the Chair of Earth Stewardship Science at the Nelson Mandela Metropolitan University (NMMU), and is the Science Director of AEON (Africa Earth Observatory Network) and NMMU's transdisciplinary ESSRI (Earth Stewardship Science Research Institute). He obtained his PhD in structural geology and tectonics at Cambridge University, UK. He has worked as postdoctoral research fellow at the Lamont-Doherty Earth Observatory of Columbia University; as a UNDP-expert in Ethiopia; and as a senior researcher at the BPI Geophysics, University of Witwatersrand, and held the Phillipson Stow Chair in Geology and Mineralogy at the University of Cape Town, South Africa (1989 - 2011). He has held long-term visiting posts at Queens University, Canada (where he was awarded an honorary DSc); Imperial College, London; MIT; University of Utrecht, Holland; IPG, Paris; and GFZ-Potsdam, Germany. He has carried out extensive field work in North and South America, Antarctica and throughout Africa. His research is focused on How the Earth Works, especially the early Earth, and the geologic evolution of Africa and its relationship to landscapes, climate and biology.

He has also written extensively on science and public policy, resource economics and global change, with an emphasis on Africa and Antarctica. He is an Honorary Fellow of the Geological Societies of the UK and of the USA; a Chartered Geologist and a Founder Member of ASSAf.

Stefan Z de Nagy Kóves Hrabár

Mr Stefan Hrabar has 45 years' experience in Engineering, Project Management and Construction of large projects in diverse industries locally and internationally. Previously Director and Managing Director of various Companies within the Murray & Roberts Group and International companies in South Africa. Involved in the Offshore Oil and Gas Projects since 1983 and the Management of South Africa's first gas offshore development offshore Mossel Bay. Previously Chairman of the NPA Offshore Oil & Gas Committee and Chairman of the South African Oil and Gas Alliance and Director of the International Pipeline Offshore Contractors Association representing Middle East and Africa. Past-President of Southern African Institution of Mechanical Engineering and responsible for the National Technology Olympiad that targets previous disadvantaged communities. He has been appointed to the Accreditation Committee of the Engineering Council of South Africa. Appointment to serve as a member of council for the Built Environment Appeals Committee. Appointed by the Minister of Transport to serve on the Port Consultative Committee of the Saldanha Port.

Meagan Mauter

Professor Meagan Mauter holds bachelors degrees in Civil and Environmental Engineering and History from Rice University, a Masters of Environmental Engineering from Rice University, and a PhD in Chemical and Environmental Engineering from Yale University. She completed postdoctoral training in the Belfer Centre for Science and International Affairs and the Mossavar Rahmani Centre for Business and Government at the Harvard Kennedy School of Government, where she was an Energy Technology Innovation Policy Fellow. At Carnegie Mellon University, she runs the Water and Energy Efficiency for the Environment (WE3 Lab) and is jointly appointed in Civil & Environmental Engineering and Engineering & Public Policy. She also holds courtesy appointments in Chemical Engineering and Materials Science & Engineering. Her present research seeks novel approaches to sustainably meet water supply in an energy constrained world by rethinking the policies surrounding water treatment, redefining the inputs to the treatment process, and re-envisioning the membranes in membrane-based water treatment processes.

Mike Shand

Dr Mike Shand headed the Water Department of Ninham Shand from 1977 until 2006 and since then has served as a consultant to Aurecon. He was Project Leader for a number of the Department of Water Affairs and Forestry's water resources studies, including planning the augmentation of the water supplies to the cities of Cape Town, Port Elizabeth and East London. He was responsible for the feasibility study which led to the construction of the Berg River Dam which supplies Cape Town, and has contributed to the various feasibility studies of the Lesotho Highlands Water Project. He has also been involved with the design of many pipelines, dam

spillways and other hydraulic structures and is currently involved in feasibility studies of desalination plants for Umgeni Water and of water reuse for Cape Town. He serves on the Executive Committee of SAAE and previously served on the committee of the Water Division of the South African Institution of Civil Engineers.

Mthozami Xiphu

Mthozami Xiphu is the Executive Chairman of The South Africa Oil and Gas Alliance (SAOGA) a position in which he started in October 2013 after serving as Executive Director from January 2013. From 1996 to 2001, he was the Head of Legal Services for the Western District Municipality in the Eastern Cape. He then joined the then Department of Minerals and Energy as the Director of Legal Services. From 2005 to 2012, Mthozami served as the Chief Executive Officer of Petroleum Agency SA, the licensing authority for oil and Gas exploration in South Africa. In this position he served as the Chairman of the Upstream Training Trust, as member of the Benguela Current Commission, and as Chairman of South Africa's Continental Shelf Claim project. From April 2011 to September 2012, Mthozami served as Chairman of the Working Group tasked by the Minister of Mineral Resources to investigate hydraulic fracturing (fracking) for South Africa.

APPENDIX 2: BIOGRAPHIES OF REVIEWERS

Luc Chevallier

Dr Luc Chevallier is the Regional Manager for Western Cape, Northern Cape and Marine at the Council for Geoscience. He obtained his PhD in Geology/Volcanology on Reunion Island in 1979 at Grenoble University. He worked on the Indian Ocean volcanoes for ten years before moving to the Council for Geoscience in 1991. He worked on geological mapping in Africa and spent 15 years researching on groundwater in the Karoo Basin.

Tom Murphy

Tom Murphy is Director of Penn State's Marcellus Centre of Outreach and Research (MCOR). With 29 years of experience working with public officials, researchers, industry, government agencies, and landowners during his tenure with the outreach branch of the university. His work has centred on educational consultation in natural resource development, with an emphasis specifically in natural gas exploration and related topics for the last nine years. He lectures globally on natural gas development from shale, the economics driving the process, and its broad impacts including landowner and surface issues, environmental aspects, evolving drilling technologies, critical infrastructure, workforce assessment and training, local business expansion, resource utilisation, and financial considerations.

MCOR's mission is to pursue science-based research and understanding for the many issues surrounding the development of shale energy in Pennsylvania and around the world. This ranges from environmental risk mitigation strategy to legal and regulatory implications of energy development in local communities. As part of MCOR's outreach, examining the role of "social license", and its many components,

is a vital feature of the shale dialogue prior to, and during the energy development phase. He provides leadership to a range of Penn State's related Marcellus research activities and events. He is a graduate of Penn State University.

Sadrack Toteu

Dr Sadrack Félix Toteu is a Programme Specialist in earth sciences at the Nairobi (Kenya) UNESCO office where he coordinates UNESCO's earth science activities in sub-Saharan African countries.

He holds two doctorates from the Nancy-Université in France and his research activities focus on the Precambrian geology of Cameroon and during the past five years, on the Pan-African belt of central Africa in the framework of the IGCP-470. He is also involved in international projects related to Precambrian geology of Africa. Within the Commission of the Geological Map of the World, he is in charge of the Tectonic map of Africa and contributed to putting the 1/1000000 scale map of Cameroon online in OneGeology.

He is a past President of the Geological Society of Africa and was Vice-President of the Geological Society of Africa for Central Africa. He is the Deputy Secretary-General for Africa of the Commission of the Geological Map of the World since 2006. He is Associate Editor of the *Journal of African Earth Sciences* and a member of the editorial board of *Precambrian Research*. He is also an invited expert for the African-European Georesources Observation System Project.

He is the recipient of several awards among which the United States Fulbright Programme Award and Excellence in Geosciences for 2007 by the Ministry of Scientific Research and Innovation in Cameroon. He is an honorary member of the Geological Society of London and a Fellow of the African Academy of Sciences.

APPENDIX 3: PROPOSED CORE RESEARCH PROJECTS

Project 1: Micro-Earthquake Detection and Deep Imaging of the Karoo

- Key Output: Define the state of natural seismic activity and the level of tectonic stability in the region, as well as the overall sub-surface structure and variable depth to the gas-shales; and to determine the ultra-deep physical and geological structures and fluid pathways beneath the Karoo.

Project 2: Groundwater Monitoring and Analysis

- Key Output: Development of Karoo groundwater monitoring and chemical analysis, to establish a natural forensic baseline for the shallow groundwater reservoirs ahead of shale gas exploration drilling and subsequent hydraulic fracturing. This should include the training of rural (preferably women) groups and high school (teachers) learners to sample water and test wells, as part of developing civic science programmes, using crowd-sourcing and mobile smart-phone technologies. It would also require advanced techniques/equipment for water chemistry analysis.

Project 3: Gas Flow Detection

- Key Output: Determine the location and flux of natural gas leakage across the Karoo region. In this process, methane (ethane, propane and butane) and CO₂ emissions must be detected and analysed using light stable isotope analysis.

Project 4: Surface and Critical Zone Changes and Karoo Ecology

- Key Outputs: Assessment through ground mapping and aerial surveys of critical zonal and environmental characteristics of ecosystems prior and during exploration drilling. Baseline flora/fauna surveys of the proposed hydraulic fracturing sites in the Karoo, and eco-physiological responses of Karoo species to hydraulic fracturing chemicals. Soil contamination potential from surface leaks. Subsequent continuous monitoring will focus on the areas immediately surrounding drill and hydraulic fracturing sites to record changes in environmental conditions, including ephemeral streams that may be polluted from wastewater. Although the exploration areas include many of the South African biomes, the most affected will be the Nama-Karoo and thicket biomes. A complete species list must be compiled at proposed hydraulic fracturing areas, highlighting species of conservation concern. Controlled experiments during which selected species must be planted in greenhouses to predict the eco-physiological responses of Karoo plants (in particular phreatophytes) to exposure of hydraulic fracturing fluid.

Project 5: Air Quality Monitoring and Seasonal Changes

- Key Outputs: Continuous monitoring of air pollution from volatile contaminants and noise pollution.

Project 6: Socio-economic Assessment and Risk Analyses

Project 7: Ecological Economics and Valuing of the Karoo Natural Services

Project 8: Karoo Open Data Base Management System

- Key Outputs: Linked to the above-mentioned projects must be the establishment and development of a large knowledge network to facilitate effective, efficient and reliable open access to a well-designed database generated by the Karoo shale gas baseline projects. This data system will form the basic framework to build value-added collaborative programme, knowledge and capacity building.







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ASSAf Research Repository

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A. Academy of Science of South Africa (ASSAf) Publications

A. ASSAf Consensus Study Reports

2016

South Africa's Technical Readiness to Support the Shale Gas Industry

Academy of Science of South Africa (ASSAf)

Academy of Science of South Africa

Academy of Science of South Africa (ASSAf), (2016). South Africa's Technical Readiness to Support the Shale Gas Industry. [Online] Available at: DOI <http://dx.doi.org/10.17159/assaf.2016/0003>
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